OPERATION AND MAINTENANCE MANUAL
ELECTRICAL INDICATION OF CONCRETE'S ABILITY TO RESIST CHLORIDE ION PENETRATION
AASHTO T277

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RESEARCH AND TECHNOLOGY

March 1995
1st Rev. November 1997
2nd Rev. October 2004

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ACKNOWLEDGEMENTS

I would like to thank Michael Byrne, of the Materials Section, for his assistance in troubleshooting the specimen cell circuit and for his critical analysis of this manual.

I would also like to thank Camie Corrente for using her hands-on experience in reviewing this manual.

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INTRODUCTION

One of the greatest problems with concrete highway structures today is that of corrosion of the reinforcing steel. This problem is especially severe in the snow belt, where de-icing salts are routinely used to keep the travel lanes free of ice and snow. The salt most typically used is sodium chloride (NaCl), which when in solution in water, is very corrosive to most ferrous alloys. Since the effect of a de-icing salt is to melt the frozen water, the product is a salt water solution. This solution penetrates into the concrete of bridge decks, piers, abutments and other roadside features like median barriers. If it penetrates deeply enough, the chloride ions in the solution can change the pH of the concrete matrix from alkaline to acidic. In this environment, the reinforcing steel can begin to oxidize. If the cross section of the steel is sufficiently reduced, the structural integrity of the element can be compromised. Long before that happens, the increased volume of the rust (compared to the original steel) will create tensile stresses in the concrete and cause cracking and spalling.

If the permeability[1] of the concrete can be reduced, the amount of chloride ions reaching the steel can be minimized. Many methods are available to achieve low permeability: Reduction of the water/cement ratio, addition of various additives and admixtures and application of a protective sealer to the concrete surface. However, it is often necessary to determine the effectiveness of these methods before they are used in an actual concrete mix; sometimes, it is also necessary to determine the permeability after the fact.

The AASHTO T 259 test, "Resistance of Concrete to Chloride Ion Penetration"), was developed to test the how well the concrete resists absorption of chloride by a standard procedure. This provides a means for comparing the effectiveness of different treatments. At the end of the test, powder samples are taken from the slab and tested for chloride content. Unfortunately, it requires ponding a 3% NaCl solution on a concrete slab for 90 days to allow the absorption of chlorides into the concrete. The concrete is then drilled to collect a powdered sample, which is then analyzed for chloride content. When results are needed in short order (which is typical in a construction operation), three months may be too long to wait.

A faster method was created for AASHTO, T 277, "Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration" (originally "Rapid Determination of the Chloride Permeability of Concrete"). This was developed by correlating data obtained using T 259 and determining relative values for permeability based on diffusion of chlorides in concrete tested with both methods. Instead of using time, gravity and diffusion characteristics of the concrete to allow penetration of the chloride ions, the ions are driven through the concrete by an electric potential. With this change, the time required is reduced to six hours (an additional day is required to prepare the specimen for testing). The electric charge passing through the concrete in this period is determined and this is used as a measure of permeability. Per AASHTO, the current is measured by a digital voltmeter[2] every thirty minutes. The apparatus that is the subject of this manual automates the test. Once the specimen cells are prepared, the operator only has to start a computer program. The equipment then takes readings (every second, which gives a more accurate result than the AASHTO method) and provides a result at the end of six hours. Additionally, it can test up to eight specimens at a time.

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[1] The permeability of a material is the tendency to allow the passage of liquids or gases through it.

[2] For those interested in the technical details, a shunt of known resistance is placed in the circuit; the voltage is measured across the shunt and the current through the shunt is then calculated (voltage=current×resistance). The current over time is plotted and the area under the curve is calculated, giving the total charge.

The AASHTO procedure is provided at the back of this manual in Appendix B, for details on the preparation of the specimens. Material in Section Nine can be ignored, as this manual supercedes that part of the method when using this apparatus.

THEORY OF OPERATION

AASHTO T277 does not directly measure the chloride permeability of the concrete as was stated in the original title (as mentioned previously, later versions of the method describe the test more accurately). What it does measure is the electrical resistance of the concrete disk used as a test specimen and how that resistance varies when chloride ions are driven through it by a constant sixty volt electrical potential.

A 3% NaCl solution is poured into the reservoir on one side of the specimen in the half of the cell and in the cell on the other side, there is a 0.01N NaOH solution (the method for preparing these solutions are detailed in Appendix C). The negative terminal of the power supply is connected to the NaCl cell half and the positive to the NaOH half. A composite of copper mesh with a brass perimeter ring in each cell adjacent to the side of the concrete insures a uniform distribution of charge over the cross-section of the concrete disk. When the power is turned on, current begins to flow through the concrete.[3] This current drives chloride ions from the NaCl solution through the concrete. As the number of ions in the concrete increases, the electrical resistance of the concrete decreases and causes the current to increase in proportion. Concrete that is less permeable will resist the penetration of chloride ions, reducing the rate at which the current increases.

Current is measured in coulombs per second and the test measures the total number of coulombs passing through the concrete. The automated control system takes a reading from each cell once every second. Therefore the readings, after being converted to amperage[4], can simply be summed together to get the total charge.

Note that some protection methods use a anti-corrosion admixture which creates a barrier between the chlorides and the steel. Some of these are ionic in nature, chemically interacting with the chlorides. These systems can result in higher coulomb values, making the concrete appear more permeable than it actually is, based solely on the coulomb values. Some concrete uses steel fibers, which can also increase apparent permeability.

EQUIPMENT COMPONENTS

The apparatus consists of four major elements (see Figure 1 for component layout):

1] The specimen cells - The cells are manufactured according to the specifications in AASHTO, but have some modifications. The NaCl half has a 3 ohm, 25 watt shunt resistor[5] epoxied to it. This resistor is wired in series with the cell and serves the

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[3] The concrete will already have been saturated with de-aerated water using the vacuum apparatus specified in the AASHTO test method.

[4] Amps are the unit of current.

[5] AASHTO specifies a 100 mV shunt, which would allow only a limit of 33 mA using the 3 ohm shunt resistor. To use a resistor that allows the maximum current that this system can provide and maintain this loss would require a maximum value of 0.375 ohms. This would reduce the ability of the control system interface card to accurately

purpose stated above. The NaOH half has a voltage divider epoxied to it and is covered with silicone adhesive to prevent shorting across the resistors where the leads are in close proximity. The voltage divider, which is wired in parallel with the cell, consists of a 25 kilo-ohm, 10 watt resistor in series with a 1 kilo-ohm, 10 watt resistor, with voltage being measured across the 1 kilo-ohm resistor[6]. Both the shunt and the divider are connected to the measurement apparatus by a an audio-type XLR three conductor plug (as seen in Figures 3 and 6). This provides positive contact and easy connection. Two of the conductors are used on each plug (looking into the plug with the clip facing down, the right pin is positive and the left pin is negative). The plugs and the corresponding jacks on the box containing the connections to the interface cards are labeled to identify which are to be attached. Figures 5 and 6 show the construction of the cells. The brass and copper conductor assembly has been replaced with a conductor plate made of 304 Stainless Steel (the assembly was originally as specified in the AASHTO Method, but it proved to be too susceptible to corrosion). The plate has 6.25 mm holes drilled on center of a series of concentric circles (figure 5). The connection of the power supplies to the cells are facilitated using high quality banana jacks and plugs. The plugs are labeled to match the corresponding cell halves. A silicone rubber has been molded into the cell over the perimeter of the conductor plate to provide a watertight seal. The cells can accommodate either a 9.5 or 10.2 cm specimen (typically taken from a core or a cylinder, respectively).

2] The power source - The source consists of two 30 volt DC power supplies, wired in series to provide the requisite 60 volts. The power switches have been removed and the supplies have been wired directly to the control system. The positive side of the source has also been independently wired to relays in the control system to allow switching off the power to any of the eight cells independently. This permits the system to shut down power to a circuit in the event excessive current is being drawn through it.

3] The computer system - The computer provides a base for the control system and its operational program. It uses a standard ISA bus for the interface card. Any functioning system meeting these minimum requirements is suitable: 640 KB RAM, 120 MB hard drive, 3.5 inch high density floppy drive, CGA monitor and adapter, 101 key keyboard, two open 8 bit ISA slots, MS-DOS v3.1 or higher, QuickBASIC v4.x. The control program is shown in Appendix A and is on the included CD-ROM.

4] The Input/Output control system - This consists of two Advantech PCL-711b multifunction I/O expansion cards (Figure 4) and two PCLD-786 digital output solid state relay boards (Figure 2). The 711 is a user addressable device that provides sixteen digital inputs (which are not used here), sixteen digital outputs (ten are used from the first card), eight analog inputs (all are used on both cards **C** the first four cells'

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measure the current. Since the ranges for the permeability are so large and the voltage drop across the shunt is at most 1.125 V (out of 60 or an error of about 1.87%), this loss was determined to be acceptable. If it was considered necessary, the program could be modified to compensate for this drop.

[6] This is required because the voltage across the cell must be kept at 60 V (±2 V) and the interface card can only measure voltages of 5 V or less. The divider has a voltage drop of [1/(1+25))]×[total voltage across divider]. When the total voltage is set to 60 V, the drop is 2.31 V, which is well below the maximum of 5 V.

shunt and voltage dividers are tracked by the first card and the second card tracks the last four) and one analog output (which is not used). The 786s are connected to the first 711b card and the relays that control the power to the cells are mounted on it. The digital outputs switch the relays on and off. There are eight opto-electrical relays mounted on the first 786 and two on the second. The first two relays on the first 786 are made to switch AC voltage (to control the power supplies) and the remainder of the relays are built to switch DC voltage (to control voltage to the cells)[7]. DC relays must be used for controlling the cell power, because the AC type tend to “latch” on to the signal and fail to switch off. The analog inputs are used to measure voltages: eight are used to measure the voltage across the shunt resistors, the other eight are used to measure the voltage across the voltage dividers. The 711b's are controlled by the operational program, which activates their functions as necessary. The wiring of the system is shown in Figure 1.

[7] The relays allow the 711b to control voltages above its maximum of 10 volts. The AC relays are rated for 250 VAC at 3 amps. The DC relays are rated for 100 VDC at 1 amp. This is more than sufficient to control the devices connected to them.

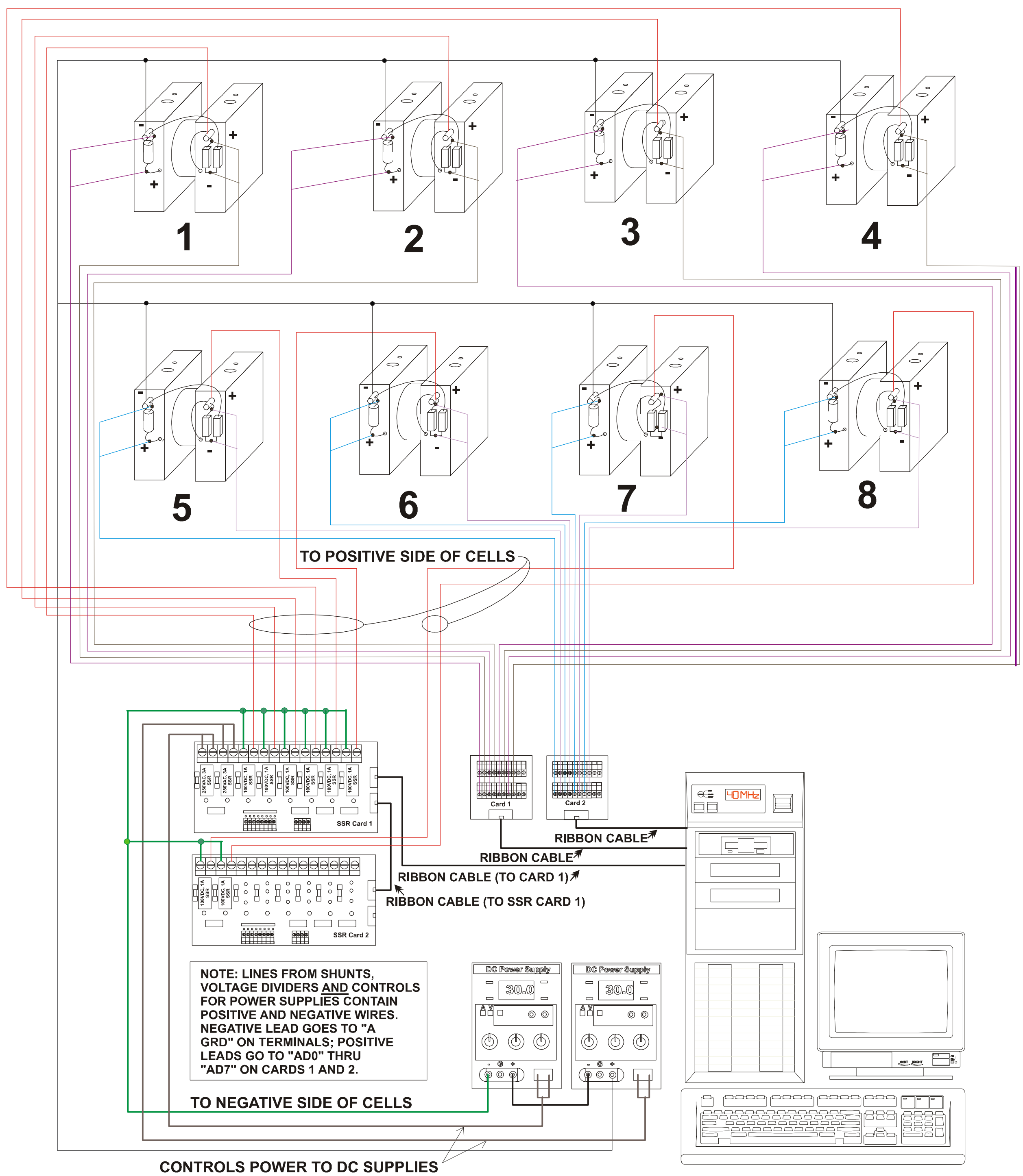

Figure 1 - Equipment Component Layout and Wiring

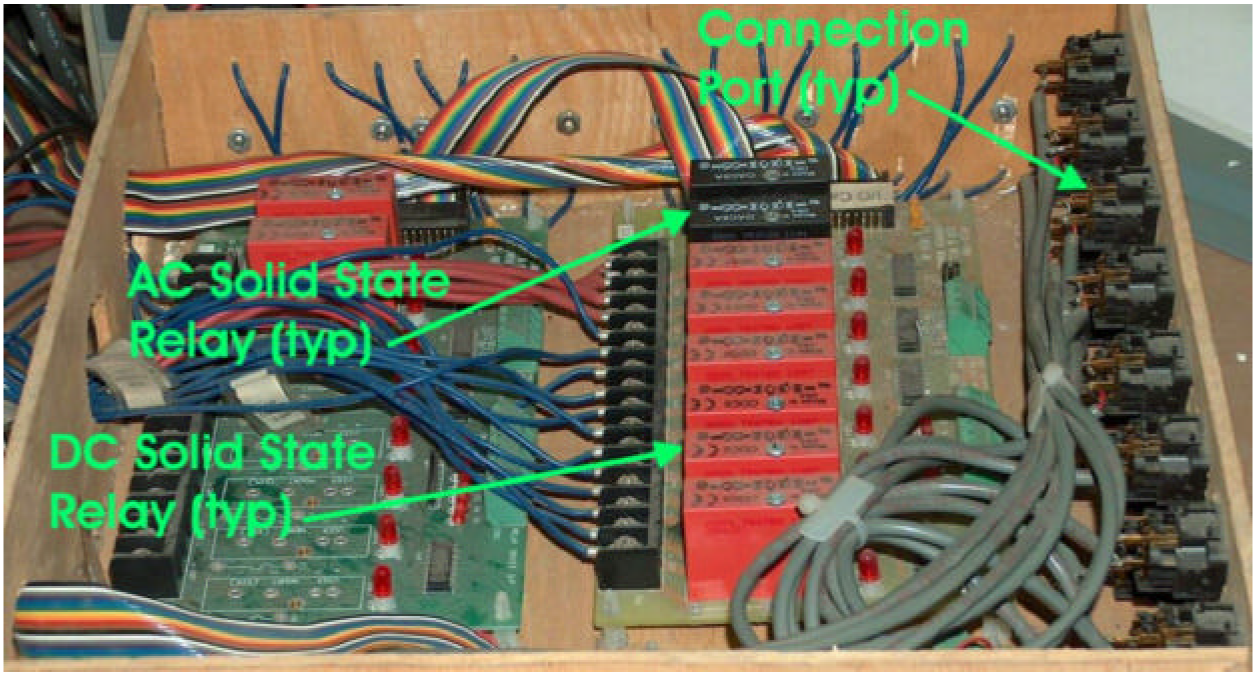

Figure 2 – Electronic Assembly

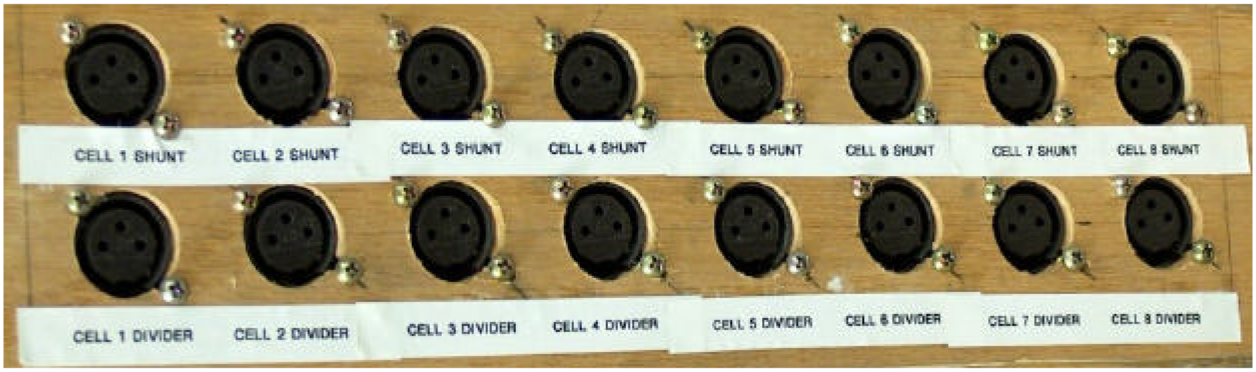

Figure 3 – Cell Connection Ports

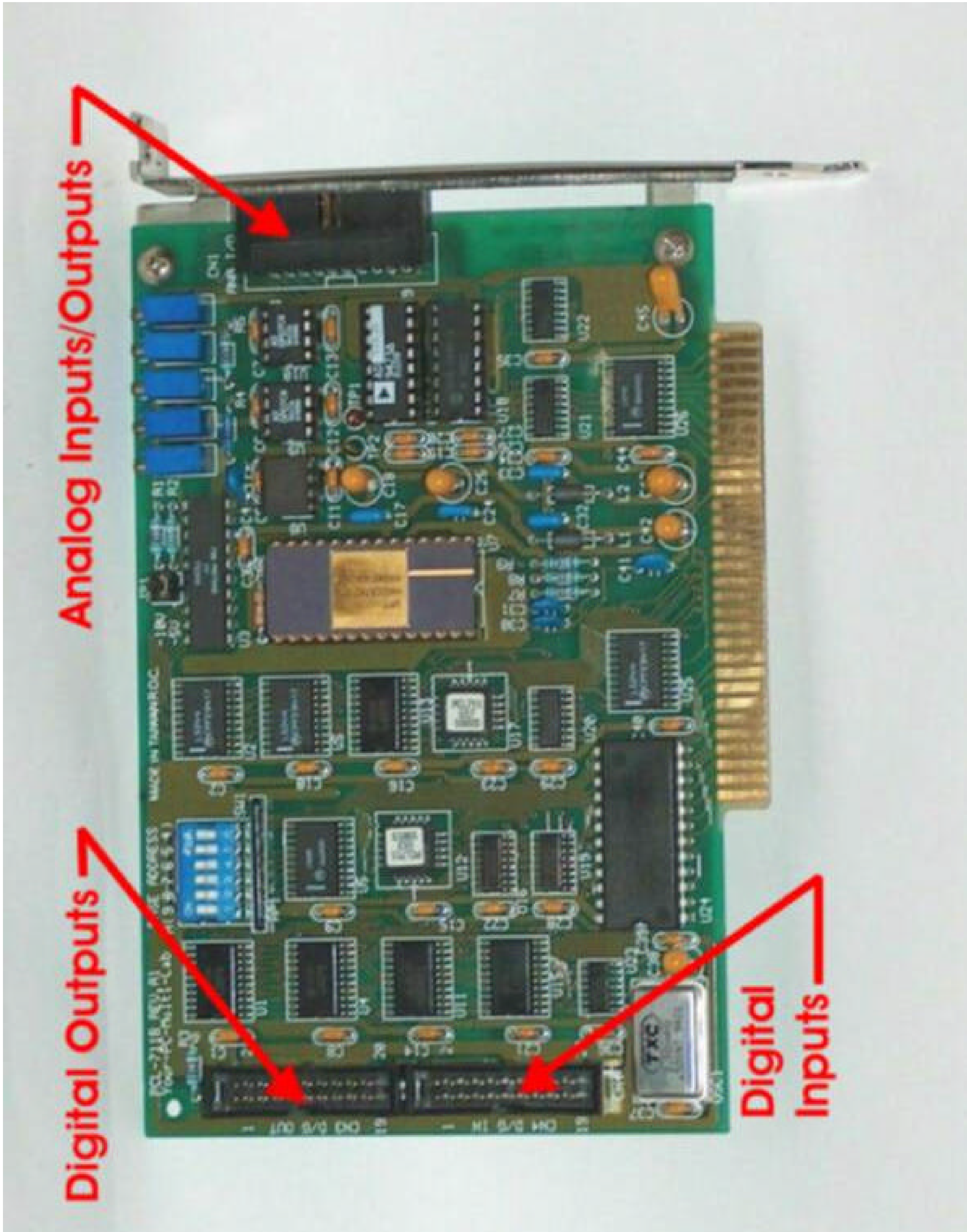

Figure 4 – Advantech PCL-711b Interface Card

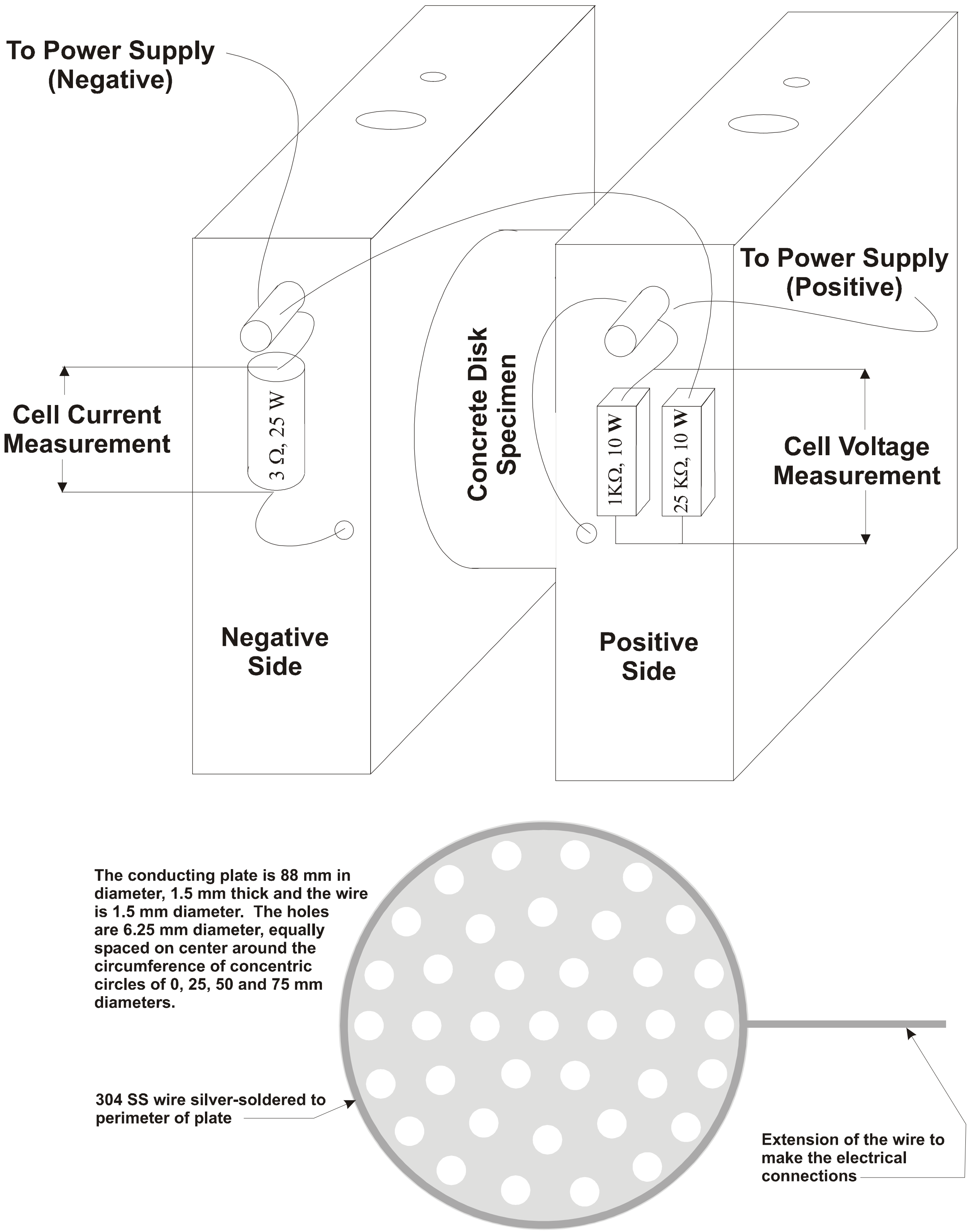

Figure 5 - Specimen Cell Construction

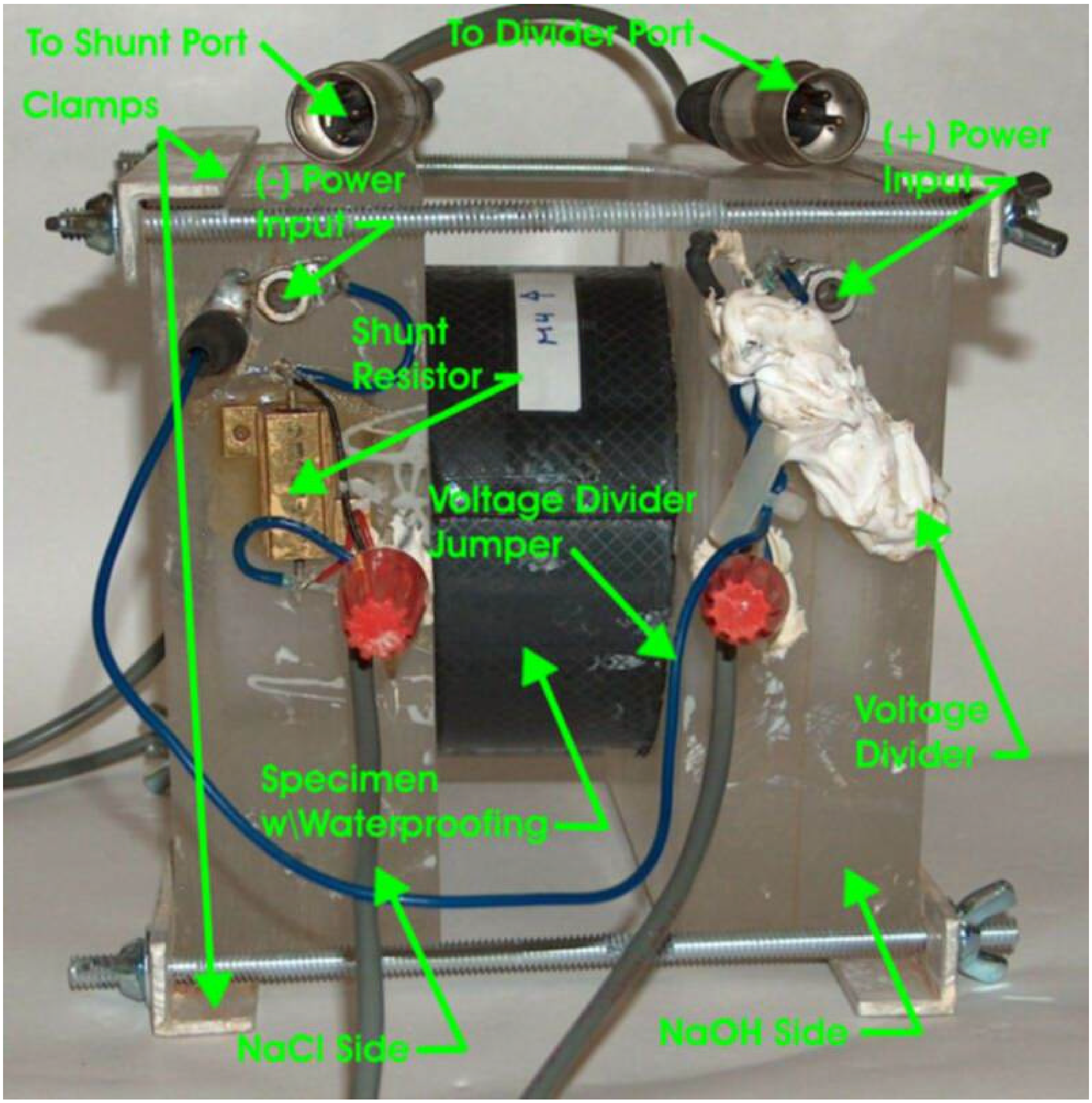

Figure 6 – Assembled Permeability Test Cell

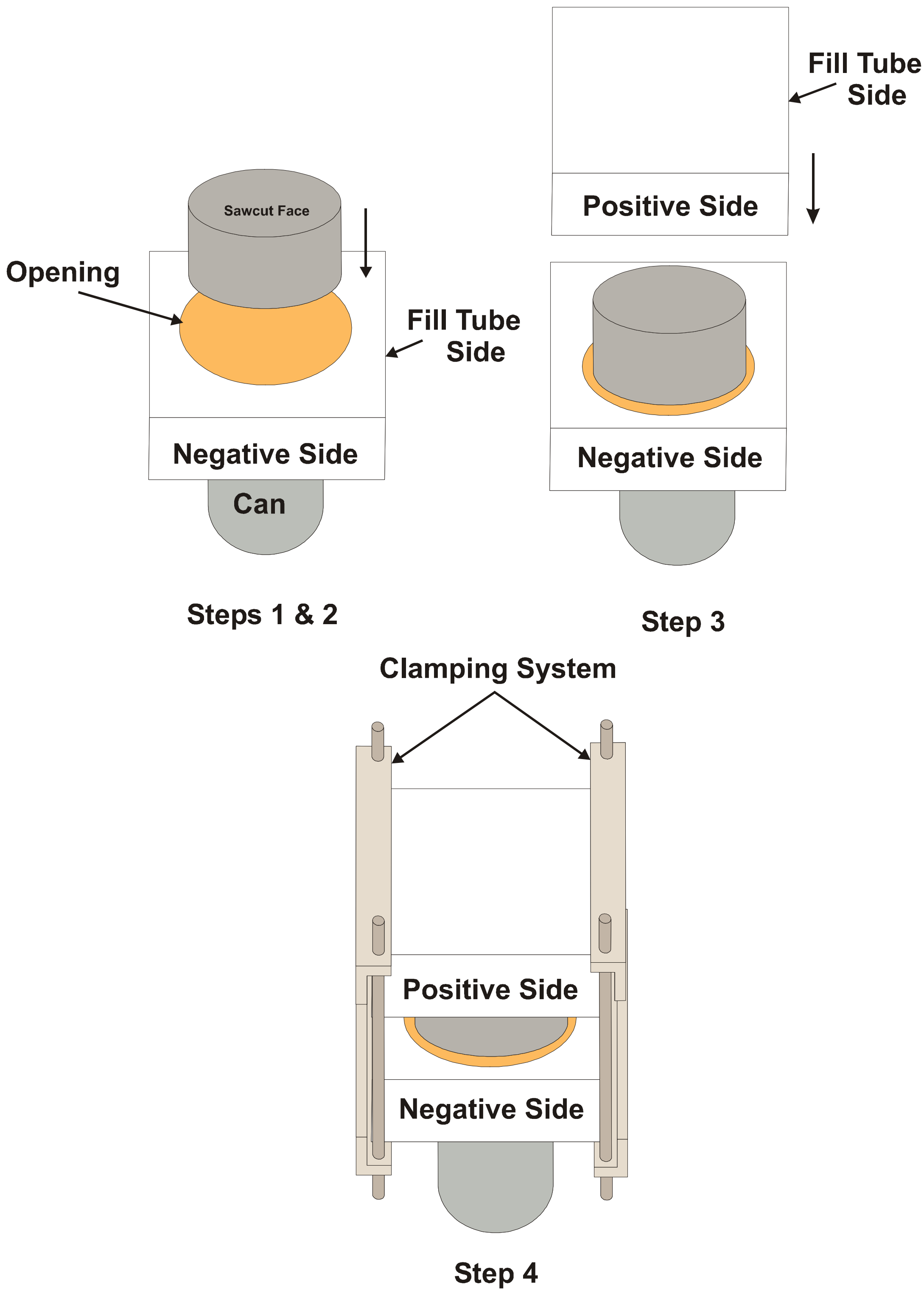

Figure 7 - Assembly of Test Cell

OPERATION OF TEST APPARATUS

There is a recommended variation in the specimen preparation as given in T 277. In place of an epoxy, a material similar to a preformed sheet waterproofing membrane (a skylight roofing underlayment) is wrapped around the circumference of the specimen to seal it. This material is easier and less hazardous to apply to the concrete. It is equally effective in containing the moisture within the specimen. The material is cut to size (5.7 × 30 cm for a 9.5 cm specimen diameter or 5.7 × 33.7 cm for a 10.2 cm specimen) and warmed lightly with a heat gun. It is then wrapped around the specimen, working out any bubbles of air that may be trapped underneath. There will be a slight overlap and the edges will need to be trimmed back to the flat faces. Prior to applying the material, transfer the specimen designation to one of the faces if it is marked on the side. If the permeability of the specimen is expected to be high, it may be necessary to waterproof the specimen using a marine grade fiberglass or an epoxy. The underlayment tends to soften and deform when exposed to the temperatures that may be generated by highly permeable concrete during testing.

The first step after preparing the specimens per AASHTO T277[8] is to set the specimens in the cell (see Figure7 for a diagram of this procedure).

1] First, lightly towel the specimen until it is surface dry and apply a label with the specimen designation to the waterproofing material.
2] Place the side of the cell labeled "Negative Side" on top of a four inch high by three inch diameter can, with the reservoir facing up (the conductive plate should be on top).
3] Then, place the troweled face (if applicable) of the specimen in the opening above the reservoir, centering it.
4] Place the other side of the cell, which is labeled "Positive Side", such that the opening is centered over the other end of the specimen. The two halves must be oriented as a mirror pair (the shunt and the voltage divider must be on the same side of the cell).
5] Holding the assembly in position, use the provided clamps to hold the top and bottom of the assembly securely in place. When tightening the wingnuts, tighten all evenly to keep the cell halves parallel and the specimen centered in the openings. ***Be careful not to allow the clamps to touch any exposed electrical conductors, as this may result in a short circuit.*** It is ***very important*** that a good seal is created; it ***must be*** waterproof. An assembled cell is shown in Figure 6.

When all the specimen cell assemblies are complete, the next step is to add the solutions to the cell reservoirs. Orient the assembly so that the fill holes are on top. Fill the reservoir of the "negative" side of the cell with the NaCl solution, using a funnel in the fill (larger) hole. Keep the funnel from dropping down far enough that it seals the opening. This allows the solution to flow more freely without backing up in the funnel. Then fill the reservoir of the "positive" side of the cell with the NaOH solution. ***Caution must be excerised when working with the NaOH solution; gloves and***

[8] AASHTO specifies that only the top of the specimen be used, but RIDOT uses three slices from the same cylinder (or core, if possible). This reduces the number of cylinders that need to be cast. Disks cut from the top and middle of the cylinder or core tend to have higher permeabilities, possibly due to bleed water or greater density due to the standard rodding procedure, but this can be factored in when analyzing the results. However, it is therefore important to note the part from which the cylinder or core that each specimen was cut.

safety glasses should be worn at all times when handling the solution due to its corrosive nature. Spilled material should be cleaned immediately using appropriate measures. Fill the reservoirs only to the bottom of the fill tubes and slow down the flow rate to a trickle as you approach the top of the reservoir to prevent overflow through the vent tube. If the reservoirs are filled beyond this point, they may overflow as the solutions heat. Watch for leaks around the perimeter of the specimen and tighten the clamping system if necessary.

Once the specimen cells have been prepared, the next step is to connect them to the data acquisition and control system. The leads are all labeled (see Figure 1 for the wiring diagram if the labels are damaged). Be careful to wire the system correctly; if not, the resulting short circuit could damage the equipment. Any number up to eight can be connected, but start from the lowest numbered channel (one) and continue until all of the specimen cells to be used are connected. The banana plug attached to the voltage divider on the NaOH side of the cell must be plugged into one of the jacks on the NaCl side (as shown in Figure 6)

The software that runs the test is essentially automatic. When the computer is turned on, type “T” at the C:>\ prompt to run the software. A title screen will be presented and the operator will be prompted to start the program by pressing any key. The operator is then prompted to turn on the switches on the power center for the supplies. The name of the test and the number of specimens (one to eight) to be tested is then inputted. Data describing the test is entered at the prompts and it is recommended that the following format is used:

Jamestown Bridge Overlay [A1B A1M A1T A2B A2M A2T] [C:8-15-92 9-12-92]

The name of the test is first, followed by the specimen designations from cell one to the last cell and completed by the cast date and the test date. Any format can be used, but this keeps all of the pertinent tracking information with the test data. Note that the specimens are named using the relative position in the core/cylinder (B - bottom, M – middle, T – Top).

The operator can halt the test at any time by pressing the S key. The computer will shut down the power to a cell if the current through the cell is greater than 375 mA.[9] If the voltage varies too much, the program will record it in the data file. The program will complete at the end of six hours without intervention and provide a total charge for each specimen (stored in RESULTS.DAT), as well as the current levels in each cell every fifteen minutes (stored in PLOT.DAT). Power to the supplies will be disconnected at this point, but the switches on the power center should still be shut off before handling the cells, as a safety precaution.

Each relay is protected with a fuse with a 3A 250V rating. The fuses were originally mounted on the relay boards, but it used a pigtail type (with a wire soldered on to each end of the fuse and then pushed into a spring terminal on the board). These proved harder to obtain than the standard type, so fuseholders were wired to the original connections. If a circuit malfunctions, checking the fuse is the first step. The cause of the overload should still be determined before replacing a fuse, as the circuit should never draw anything approaching 3 amps. If uncertain as to how to go about this, consult someone with experience troubleshooting electrical equipment.

[9] A current reading of 375 mA or more indicates that the total charge will be at least 4000 coulombs (and probably much higher if occurring early in the test). AASHTO T277 gives a value of 4000 as extremely permeable concrete. Therefore, if the current gets that high, it can be safely assumed that the permeability is high.

Appendix A
Automation Control Computer Program Source Code

The program accesses the driver functions for two Advantech PCL-711b MultiLab Cards (an I/O card with digital and analog input and output capabilities). These cards provide analog input capabilities that are used for measuring the voltages across the shunt resistors and the low resistance leg of the voltage dividers. The program also uses one card to control a relay board which switches on the power supplies and controls power to the cell assemblies.

The program first dimensions the array required by the subroutines controlling the the I/O cards and for temporary storage of data during the test. The program then prompts the operator for input regarding the test: Test data description and number of channels required (for the number of test specimens). Validation is performed on the input for the number of channels. The next loop sets the values that will insure that unused channels are not powered and activates power for those that should be.

The BASIC TIMER function is then initialized so that the time increments for each reading can be set and so that the test can be set to run for six hours (21,600 seconds). This is done in intervals of fifteen minutes (900 seconds), after which the timer is reset. The next loop checks the current level for each cell and shuts down power to that cell if the current is over 375 mA.

At each fifteen minute interval, the data is written to disk. Writing to disk at shorter intervals might interfere with the timing of the data collection. At the end of the test, the final results are written to disk and the system is powered down.

There are three subroutines. The first reads analog data from the inputs. The second allows the operator to shut down the program at any time (using the INKEY$ function). The third uses digital output to control the SSR relay boards, which in turn controls power to the power supplies and the cells.

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'THIS PROGRAM OPERATES PERMEABILITY TEST EQUIPMENT ACCORDING TO AASHTO T277.
'  THIS TEST MEASURES THE CURRENT PASSING THROUGH A TEST CELL COMPOSED OF A
'  CONCRETE DISK WITH A SODIUM CHLORIDE RESERVOIR ON ONE FACE AND SODIUM
'  HYDROXIDE ON THE OPPOSITE FACE. THE VOLTAGE POTENTIAL ACROSS THE CELL
'  DRIVES CHLORIDE IONS THROUGH THE CONCRETE.  THE DEGREE TO WHICH THE
'  CURRENT FLOW INCREASES OVER THE SIX HOUR TEST IS A MEASURE OF THE FLOW OF
'  CHLORIDE IONS THROUGH THE CONCRETE.  THE CURRENT FLOW OVER TIME IS
'  MEASURED IN COULOMBS AND IS CONSIDERED AN INDICATOR OF HOW PERMEABLE THE
'  CONCRETE IS.  THERE ARE TWO ADVANTECH PCL711B INTERFACE  CARDS INSTALLED
'  IN THE COMPUTER.  THESE CARDS PROVIDE EIGHT ANALOG INPUTS, SIXTEEN DIGITAL
'  INPUTS, SIXTEEN DIGITAL OUTPUTS AND ONE ANALOG OUTPUT EACH. THERE ARE EIGHT
'  PERMEABILITY CELLS ATTACHED, IN PARALLEL, TO A SIXTY VOLT POWER SOURCE
'  (TWO THIRTY VOLT POWER SUPPLIES IN SERIES).  IN SERIES WITH EACH CELL IS
'  A THREE OHM SHUNT RESISTOR (RATED FOR TWENTY-FIVE WATTS).  THESE SHUNTS
'  ALLOW THE INTERFACE CARDS (CHANNELS ONE THROUGH SEVEN, ODD, ON EACH CARD)
'  TO MEASURE THE VOLTAGE ACROSS THE SHUNT, FROM WHICH THE CURRENT CAN BE
'  DERIVED (THE ADVANTECH BOARDS CAN ONLY MEASURE VOLTAGE DIRECTLY).
'  READINGS ARE TAKEN APPROXIMATELY EVERY SECOND.  HOWEVER, SINCE THE VALUE
'  FOR THE TOTAL CHARGE IS CALCULATED ASSUMING THE AMOUNT OF CURRENT
'  MEASURED FOR ONE SECOND (COULOMBS ARE AMPS TIMES SECONDS), THE PRECISE
'  AMOUNT OF TIME ELAPSED IS NECESSARY (AND IS MEASURED) TO CALCULATE A
'  MORE EXACT VALUE FOR THE TOTAL CHARGE PASSING THROUGH THE SPECIMEN.
'  THERE IS ALSO A SIMPLE RESISTOR NETWORK IN PARALLEL WITH THE SPECIMEN
'  CELL, WHICH ACTS AS A VOLTAGE DIVIDER TO ALLOWS THE INTERFACE CARDS TO
'  READ THE VOLTAGE ACROSS THE CELLS (ON CHANNELS TWO THROUGH EIGHT, EVEN,
'  ON THE EACH CARD; THE VOLTAGE DIVIDER IS NECESSARY TO LOWER THE
'  VOLTAGE LEVEL BELOW FIVE VOLTS, WHICH IS THE MAXIMUM FOR THE ANALOG
'  INPUTS). AN ADVANTECH PCLD-786 RELAY BOARD IS CONNECTED TO THE EACH CARD.
'  THIS CARD PLACES RELAYS IN LINE WITH THE DIGITAL OUTPUTS, ALLOWING THEM TO
'  CONTROL HIGHER VOLTAGE DEVICES. THE FIRST TWO CHANNELS CONROL THE TWO
'  POWER SUPPLIES.  THE NEXT EIGHT CONTROL THE POWER TO EACH OF THE EIGHT
'  SPECIMEN CELLS (SIX ON THE FIRST RELAY CARD AND THE FIRST TWO ON THE SECOND)
'  SWITCHING THEM ON AS REQUIRED FOR THE NUMBER OF SPECIMENS TO BE TESTED AND
'  SWITCHING THEM OFF AT THE END OF THE TEST OR IF THE CURRENT RISES TOO HIGH.

'CONSTANTS:

'  CORR - A CORRECTION FACTOR FOR VARIATIONS IN THE RESISTORS USED IN EACH OF THE
'    VOLTAGE DIVIDERS.

'VARIABLES (INCLUDING SUBROUTINE LOCAL VARIABLES):

'  AMPM$ - A STRING VARIABLE THAT CONTAINS EITHER "am" OR "pm" AND IS USED
'    TO DISPLAY THE TWELVE HOUR TIME OF THE TEST.
'  ARY1%, ARY2% - DIMENSIONED ARRAYS REQUIRED BY THE INTERFACE CARDS.
'  CHARGE - AN ARRAY CONTAINING THE CALCULATED VALUES OF THE TOTAL CHARGES
'    PASSING THROUGH THE CONCRETE SPECIMENS  (SUMMED AFTER FOR EACH SECOND
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'     OF THE TEST; ONLY CONTAINS VALUES IN THE ODD INDEXED VALUES OF THE
'     ARRAY, THE REST ARE DUMMY SPACES CORRESPONDING TO CELL VOLTAGE
'     POTENTIALS).
'   CHECK - THIS TWO-DIMENSIONAL ARRAY STORES THE NUMBER OF TIMES THAT THE
'     CURRENT THROUGH A SHUNT RESISTOR EXCEEDS 375 MILLIAMPS AND WHETHER
'     THE CIRCUIT HAS BEEN SHUT OFF PREVIOUSLY. IF THE VALUE RISES TO 100
'     THAN THE DIGITAL OUPTPUT CHANNEL FOR THAT SHUNT IS SET TO ZERO BY
'     ALTERING THE VALUE OF DAT (STOPPING CURRENT FLOW THROUGH THAT
'     CIRCUIT). ONCE THE CIRCUIT IS SHUT OFF THE VALUE, THE SECOND COLUMN OF
'     THE ARRAY IS SET TO ZERO (HAVING BEEN INITIALIZED TO ONE). THIS IS
'     NECESSARY TO KEEP THE PROGRAM FROM FURTHER ALTERING THE VALUE OF DAT.
'   CONDITION$ - AN ARRAY CONTAINING A STRING VALUE INDICATING WHETHER OR
'     NOT THE VOLTAGE ACROSS THE SPECIMEN CELL WAS MANTAINED AT THE
'     SPECIFIED 60 VOLTS (ñ1 VOLT).
'   CONTROL$ - A VARIABLE USED TO STORE THE VALUE OF THE INKEY$ FUNCTION,
'     WHICH DETERMINES WHETHER THE OPERATOR WISHES TO TERMINATE THE TEST.
'   CORR - A CORRECTION FACTOR FOR THE CELL VOLTAGES BASED ON PRECISE
'     MEASUREMENTS OF THE DIVIDER RESISTORS.
'   CORREMP - AN ARRAY CONTAINING AN ADDITIONAL CORRECTION FACTOR FOR EACH OF
'     THE CELL VOLTAGES BASED ON ACTUAL MEASURMENTS OF THE VOLTAGES IN
'     COMPARISON TO THE CALCULATED VALUES BASED ON THE A/D INPUTS.
'   DAT% - DIMENSIONED ARRAY REQUIRED BY INTERFACE CARD. USED TO FEED
'     VALUES TO CARDS THROUGH DRIVER.
'   DESCRIP$ - AN OPERATOR ENTERED STRING VALUE FOR TO DESCRIBE THE TEST
'     BEING CONDUCTED.
'   DUMMY - A VARIABLE USED ONLY TO ALLOW THE OPERATOR TO START THE TEST.
'   ENDTEST - A VARIABLE THE NUMBER OF SECONDS AFTER MIDNIGHT THAT THE TEST
'     WILL END THIS IS USED TO CALACULATE THE TIME FOR DISPLAY.
'   ENDTEST$ - A STRING VARIABLE CONTAINING THE TIME THAT THE TEST WILL END.
'   FINISH - A VARIABLE USED TO DETERMINE THE END OF THE EXACT ELAPSED TIME
'     BETWEEN READINGS FROM THE PCL-711 CARD TO MEASURE THE VOLTAGE FROM THE
'     A/D INPUTS.
'   HOUREND - A CALCULATED VARIABLE THAT CONTAINS THE HOUR OF THE TIME THAT THE
'     TEST WILL END.
'   HOUREND$ - A STRING VARIABLE THAT CONTAINS THE HOUR (AM/PM) OF THE TIME
'     THAT THE TEST WILL END.
'   HR - A VARIABLE USED TO RETRIEVE THE HOUR OF THE TIME AS OBTAINED FROM THE
'     BASIC TIME$ FUNCTION.
'   MINEND - A CALCULATED VARIABLE THAT CONTAINS THE MINUTES OF THE TIME THAT
'     THE TEST WILL END.
'   MINEND$ - A STRING VARIABLE THAT CONTAINS THE MINUTES OF THE TIME THAT THE
'     TEST WILL END.
'   SECEND - A CALCULATED VARIABLE THAT CONTAINS THE HOUR OF THE SECONDS THAT
'     THE TEST WILL END.
'   SECEND$ - A STRING VARIABLE THAT CONTAINS THE SECONDS OF THE TIME THAT THE
'     TEST WILL END.
'   SHUNT - A VARIABLE THAT CONTAINS THE VALUE IN OHMS OF THE RESISTOR USED TO
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Automated Permeability Test Manual

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'    MEASURE THE CURRENT FLOW THROUGH THE CONCRETE.
'  START - A VARIABLE USED TO DETERMINE THE BEGINNING OF THE EXACT ELAPSED
'    TIME BETWEEN READINGS FROM THE PCL-711 CARD TO MEASURE THE VOLTAGE FROM
'    THE A/D INPUTS.
'  STARTTIME - A VARIABLE CONTAINING THE TEST STARTING TIME.
'  STATE$ - A VARIABLE, WHICH WHEN SET TO "stop", INDICATES TO THE SUBROUTINE
'    BREAKOUT THAT THE TEST IS TO BE STOPPED IMMEDIATELY.
'  T$ - A STRING VARIABLE USED TO RETRIEVE THE CURRENT TIME USING THE BASIC
'    TIME$ FUNCTION.
'  TWELVEHOURTIME$ - A STRING VARIABLE THAT CONTAINS THE CALCULATED 12 HOUR
'    TIME AS DETERMINED BY THE CURRENT TIME AS RETRIEVED FROM THE BASIC TIME$
'    FUNCTION.
'  VOLTAGE - AN ARRAY CONTAINING THE MEASURED VOLTAGES FOR EACH SHUNT (THE
'    ODD NUMBERED INDEX VALUES) AND THE MEASURED VOLTAGES ACROSS EACH
'    SPECIMEN CELL (THE EVEN NUMBERED INDEX VALUES).  A CORRECTION OF 0.00244
'    REPLACED CONVERTS THE BINARY INPUT TO VOLTAGE (THE RESOLUTION OF THE A/D
'    CONVERTOR IS TWELVE BITS; THEREFORE, THERE ARE 4096 STEPS THROUGHOUT THE
'    VOLTAGE RANGE, GIVING 0.00244 FOR THE INVERSE FOR HALF OF THE RANGE,
'    2048 STEPS OR FIVE VOLTS).  NEW VALUES ARE RECORDED EVERY SECOND. NOTE
'    THAT THE SHUNT RESISTORS ARE THREE OHMS AND THERE IS AN OP AMP FOR EACH
'    SHUNT WITH A GAIN OF FIVE, REQUIRING DIVISION BY FIFTEEN TO ARRIVE AT THE
'    CURRENT.  THE RESISTOR NETWORK FOR EVERY SPECIMEN CELL REDUCES THE
'    VOLTAGE ACROSS EACH BY A FACTOR OF TWENTY, REQUIRING A CORRECTION OF
'    TWENTY WHEN CALCULATING THE VOLTAGE.
'  VOLTCOUNT - AN ARRAY THAT TRACKS WHEN THE CELL VOLTAGE FALLS OUTSIDE THE
'    SPECIFIED RANGE (60 V, ñ1V).  IF ONE THOUSAND SUCCESSIVE READINGS ARE
'    OUTSIDE THE RANGE, THE VALUE OF CONDITION$ IS CHANGED TO INDICATE THAT.

'SUBROUTINES:

'  ADCONV - CONVERTS THE VOLTAGES (ACROSS THE SHUNTS AND THE SPECIMEN CELLS)
'    FROM THE CHANNELS OF THE FIRST INTERFACE CARD AND FROM THE FIRST FOUR
'    CHANNELS OF THE SECOND CARD TO BINARY NUMERIC VALUES WHICH CAN BE
'    MANIPULATED BY THE COMPUTER.
'  BREAKOUT - STOPS THE TEST AT OPERATOR REQUEST.
'  DACONV - CONVERTS A BINARY VALUE TO A VOLTAGE (NOT CURRENTLY USED).
'  DIGITALOUTPUT - SENDS AN ON/OFF (BINARY 0/1) SIGNAL TO THE THE FIRST
'    INTERFACE CARD TO SWITCH ON THE POWER SUPPLIES AND CONTROL CURRENT FLOW
'    TO EACH SPECIMEN CELL.

'DATA FILES:

'  PLOT.DAT - THIS FILE STORES THE CURRENT READINGS AT FIFTEEN MINUTE
'    INTERVALS FOR PLOTTING THE CURVE FOR EACH SPECIMEN CELL.  IT ALSO STORES
'    THE TEST DESRIPTION.
'  RESULTS.DAT - THE FILE WHERE THE TEST RESULTS ARE STORED.  THE FILE ALSO
'    STORES A DESRIPTION OF THE THE TEST.  IT IS ACCESSED THROUGH AN APPEND
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'    COMMAND SO THAT THE SAME FILE CAN STORE THE RESULTS OF SEVERAL DIFFERENT
'    TESTS.

'THESE LINES DECLARE THE SUBROUTINES AND THE VARIABLES THAT WILL BE PASSED
'    BETWEEN THE SUBROUTINES AND THE MAIN PROGRAM MODULE:

DECLARE SUB DigitalOutput (dat)
DECLARE SUB BreakOut (CHARGE(), finish, first, state$)
DECLARE SUB ADConv (VOLTAGE(), finish, start)
DECLARE SUB to12 (twelvehourtime$)

DIM ary1%(1000), ary2%(1000), CHARGE(32), check(32, 2), condition$(32), dat%(32), VOLTAGE(40), voltcount(40)

'THESE TWO LINES OPEN THE DATA FILES:

OPEN "c:\permfile\results.dat" FOR APPEND AS #1
OPEN "c:\permfile\plot.dat" FOR APPEND AS #2

CLS  'CLEARS SCREEN OF ALL CHARACTERS/RESETS THE CURSOR TO UPPER LEFT CORNER:

'THE FOLLOWING LINES GENERATE THE PROGRAM TITLE SCREEN AND PROMPT THE USER TO
'    START THE PROGRAM:

PRINT "        -----------------------------------------------------------------
PRINT "        |            RHODE ISLAND DEPARTMENT OF TRANSPORTATION            |"
PRINT "        |               RESEARCH AND TECHNOLOGY DEVELOPMENT               |"
PRINT "        |    RAPID DETERMINATION OF CHLORIDE PERMEABILITY OF CONCRETE     |"
PRINT "        |                            AASHTO T277                          |"
PRINT "        |                                                                 |"
PRINT "        |                         AUTOMATION PROGRAM                      |"
PRINT "        ------------------------------------------------------------------"
PRINT
PRINT
PRINT
PRINT
PRINT
PRINT
PRINT
PRINT
PRINT
PRINT
PRINT
PRINT
PRINT
PRINT "                                   PRESS ANY KEY TO CONTINUE"
INPUT "", dummy
CLS
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'THESE LINE PROMPTS THE USER TO TURN ON THE TEST CELL POWER SUPPLIES:

       LOCATE 12, 5
       PRINT "Please turn on the cell power supplies (AUX1 and AUX2 on the"
       INPUT "power center) and press return when done:", dummy$
       CLS

'THESE LINES STORE THE INITIAL DATA FOR THE TEST IN THE FILE "RESULTS.DAT":

PRINT "Enter a description of the test data"
INPUT descrip$
PRINT #1,
PRINT #1, "DATE OF TEST: "; DATE$     'PRINTS DATE TO FILE
       CALL to12(twelvehourtime$) 'ACCESSES SUBROUTINE TO GET 12 HOUR TIME
PRINT #1, "START TIME OF TEST:"; twelvehourtime$ 'PRINTS TIME TO FILE
PRINT #1, descrip$  'PRINTS TEST DESCRIPTION TO FILE

'THIS LINE ALLOWS THE OPERATOR TO  SELECT THE NUMBER OF SPECIMENS TO BE
'     TESTED:

A:   INPUT "Enter the number of specimens to be tested (1 to 8):", NUMBER

'THIS LOOP VALIDATES THE INPUT FOR THE VARIABLE NUMBER:

IF NUMBER > 8 OR NUMBER < 1 OR (NUMBER <> INT(NUMBER)) THEN

       PRINT "That values is not acceptable. Please enter a integer number"
       PRINT " from 1 to 8."
       GOTO A

END IF

'THIS LINE RECORDS THE STARTING TIME FOR THE TEST:

CALL to12(twelvehourtime$)
starttime$ = twelvehourtime$

'THIS LOOP SETS THE NUMBER OF DIGITAL OUTPUTS, BASED ON THE VALUE OF NUMBER.
'     THEY DO THIS BY SETTING VALUES IN THE ARRAY CHECK TO INDICATE THAT THE
'     UNUSED CHANNELS ARE SHUT DOWN AND ALSO CALL THE SUBROUTINE
'     DigitalOutput AND PASSES THE VALUE OF DAT TO IT TO CONTROL THE NUMBER
'     OF ACTIVE OUTPUT CHANNELS:


 'THESE LINES SETS DAT TO ACTIVATE THE POWER SUPPLIES AND THE REQUIRED
 '    SPECIMEN CELL CIRCUITS:
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  dat = 2 ^ (NUMBER + 2) - 1

       FOR I = ((NUMBER * 2) + 1) TO 15 STEP 2
              check(I, 2) = 0
       NEXT I


    CALL DigitalOutput(dat)


'THESE LINES ENTER INITAL VALUES INTO THE FILE "PLOT.DAT":

 'THIS LINE PRINTS THE STRING CONTAINED IN DESCRIP$ IN THE FILE "PLOT.DAT"

   PRINT #2, descrip$
   PRINT #2, "The date is: "; DATE$  'PRINTS THE DATE TO FILE "PLOT.DAT"
       CALL to12(twelvehourtime$)    'ACCESSES SUBROUTINE TO GET 12 HOUR TIME
   PRINT #2, "The time is: "; twelvehourtime$  'PRINTS THE TIME TO FILE "PLOT.DAT"

 'THIS LINE PRINTS A HEADER ROW TO FILE "PLOT.DAT"

   PRINT #2, "Seconds  No. 1   No. 2   No. 3   No. 4   No. 5   No. 6   No. 7   No. 8"

'THIS LOOP SETS ALL THE VALUES IN THE ARRAY CHECK TO ZERO; THIS IS DONE TO
'    PREVENT CHANGING OF THE DIGITAL OUTPUT SETTING ONCE INITIALIZED:

   FOR m = 1 TO 20
       check(m, 1) = 0
       check(m, 2) = 1
   NEXT m

'THIS LOOP INITIALIZES THE ARRAY CONDITION$:

   FOR n = 2 TO 20 STEP 2
       condition$(n) = "The voltage across the specimen cell was maintained at sixty volts (plus/minus one volt)."
   NEXT n

'   count = 1   'THIS LINE INITIALIZES COUNT

'THESE LINES ALLOW THE PROGRAM TO CALCULATE THE ENDING TIME OF THE TEST AND
'    DISPLAY IT:

   endtest = TIMER + 21600

   hourend = INT(endtest / 3600)
   minend = INT((endtest - (hourend * 3600)) / 60)
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   secend = INT((endtest - (hourend * 3600)) - (minend * 60))

   IF hourend >= 12 THEN
       ampm$ = "pm"
   ELSE
       ampm$ = "am"
   END IF

   IF hourend > 12 THEN
       hourend$ = STR$(hourend - 12)
   ELSEIF hourend = 0 THEN
       hourend$ = STR$(12)
   ELSE
       hourend$ = STR$(hourend)
   END IF

   IF minend < 10 THEN
       minend$ = STR$(minend)
       minend$ = RIGHT$(minend$, 1)
       minend$ = "0" + minend$
   ELSE
       minend$ = STR$(minend)
       minend$ = RIGHT$(minend$, 2)
   END IF

   IF secend < 10 THEN
       secend$ = STR$(secend)
       secend$ = RIGHT$(secend$, 1)
       secend$ = "0" + secend$
   ELSE
       secend$ = STR$(secend)
       secend$ = RIGHT$(secend$, 2)
   END IF

   endtest$ = hourend$ + ":" + minend$ + ":" + secend$

           PRINT "Start of test:  "; TIME$
           PRINT "End of test:  "; endtest$; " "; ampm$


'THESE FIVE LINES INITIALIZE THE TIMER FUNCTION TO ALLOW THE INTERFACE CARDS
'    TO TAKE READINGS EVERY SECOND AND INITIALIZE THE VARIABLES finish AND
'    start TO MEASURE THE ACTUAL ELAPSED TIME BETWEEN READINGS.  THEY ALSO
'    TRACK THE TIME TO ALLOW THE PROGRAM TO END THE TEST AT SIX HOURS:

   first = TIMER
   firstcount = TIMER
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   start = TIMER
b: finish = TIMER
   finishcount = TIMER


'THIS LINE CHECKS FOR THE PASSAGE OF SIX HOURS (21600 SECONDS), THE SPECIFIED
'    DURATION OF THE TEST):

IF finish - first >= 21600 THEN GOTO c

'THIS IF LOOP CHECKS TO SEE IF ONE SECOND HAS PASSED SINCE THE LAST READING
'    TO DETERMINE WHETHER IT IS TIME TO TAKE ANOTHER READING

 'THIS LINE CHECKS FOR THE PASSAGE OF ONE SECOND SINCE LAST READING:

IF finish - start >= 1 THEN
    count = count + 1

'THIS LINE CHECKS THE KEYBOARD FOR INPUT USING THE BASIC INKEY$ FUNCTION AND
 '   ASSIGNS VALUE TO CONTROL$:

      control$ = INKEY$

'THIS LOOP ALLOWS THE OPERATOR TO STOP THE TEST:

      IF control$ = "S" OR control$ = "s" THEN
             state$ = "stop"
             CALL BreakOut(CHARGE(), finish, first, state$)
      END IF

'THIS LINE ACCESSES THE SUBROUTINE ADConv TO COLLECT THE DATA FROM THE A/D
'    CONVERTERS ON THE PCL-711 CARDS:

        CALL ADConv(VOLTAGE(), finish, start)

'THE FOLLOWING LINES OUTPUT THE CURRENT DATA TO THE SCREEN:


      CLS
      LOCATE 1, 1
             PRINT "Test: "; descrip$
             PRINT "The date is "; DATE$
             PRINT "The start time is "; starttime$
             LOCATE 4, 1: PRINT "The end time is "; endtest$; " "; ampm$
               CALL to12(twelvehourtime$)
             PRINT "The current time is "; twelvehourtime$
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            PRINT USING "The elapsed time is ##### seconds (# hours and ##.## minutes, ###.##% done)"; finish - first;
INT((finish - first) / 3600); ((finish - first) / 3600 - (INT((finish - first) / 3600))) * 60; 100 * (finish - first) / 21600

'THESE LINES LOOP THROUGH THE INDEXES FOR THE CHANNELS OF THE SHUNT
'    RESISTOR CURRENTS AND CALCULATES THE CURRENT TOTAL CHARGE THAT HAS
'    PASSED THROUGH THE CONCRETE:

      FOR o = 1 TO (2 * NUMBER - 1) STEP 2
            IF VOLTAGE(o) < 0 THEN VOLTAGE(o) = 0
            CHARGE(o) = VOLTAGE(o) + CHARGE(o)      'SUMS THE CHARGE DATA

        'THIS LINE INCREMENTS CHECK IF CURRENT FLOW IS GREATER THAN 375 mA:

            IF VOLTAGE(o) >= .375 THEN check(o, 1) = check(o, 1) + 1
            PRINT USING "The current through cell no. # is #.### A. The cell voltage is ###.# V."; (o + 1) / 2; VOLTAGE(o); VOLTAGE(o + 1)
            PRINT USING "The total charge that has passed through cell no. # is ####.# coulombs."; (o + 1) / 2; CHARGE(o)
      NEXT o

'THESE TWO LINES SET UP THE MESSAGE TO PROMPT THE USER TO PRESS THE "s" OR "S"
'    KEYS IF IT IS NECESSARY TO END THE TEST:

      LOCATE 23, 1
      PRINT "Press the S key to end the test"

'THIS LOOP CHECKS THE VALUE OF check TO DETERMINE IF THE LAST ONE HUNDRED
'    READINGS WERE ABOVE 375 mA FOR THE CURRENT PASSING THROUGH THE SPECIMENS
'    AND SET THE VALUE OF dat TO SHUT DOWN THE APPROPRIATE CELL, IF ANY HAVE
'    BEEN.  THE VALUE OF dat IS THEN PASSED TO DigitalOutput AND THE CELL
'    POWER IS REMOVED.  A MESSAGE IS ALSO RECORDED IN FILE "RESULTS.DAT"
'    NOTING THE CELL NUMBER AND THE TIME:

  FOR O1 = 1 TO 15 STEP 2

      IF check(O1, 1) >= 100 AND check(O1, 2) <> 0 THEN
            dat = dat - 2 ^ (((O1 + 1) / 2) + 1)
            check(O1, 2) = 0
            CALL DigitalOutput(dat)
            PRINT #1, "Specimen cell #"; (O1 + 1) / 2; " circuit shut down at "; count; " seconds"
      END IF

  NEXT O1


'THESE LINES LOOP THROUGH THE INDEXES FOR THE CHANNELS OF THE SPECIMENS CELL
'    VOLTAGES AND COUNT THE NUMBER OF CONSECUTIVE TIMES THE VALUE IS MORE THAN
'    ONE VOLT ABOVE OR BELOW THE SIXTY VOLTS SPECIFIED.  IF THE NUMBER REACHES
'    1000, A MESSAGE IS RECORDED FOR STORAGE IN THE FILE "RESULTS.DAT".
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'    OTHERWISE, THE COUNT IS RESET TO ZERO:

       FOR p = 2 TO 16 STEP 2
         IF VOLTAGE(p) > 61 OR VOLTAGE(p) < 59 THEN   'CHECKS THE VOLTAGE ACROSSE CELLS
           voltcount(p) = voltcount(p) + 1
             IF voltcount(p) >= 1000 THEN  'CHECKS FOR ONE THOUSAND CONSECUTIVE INSTANCES OF VOLTAGE OUTSIDE RANGE
               condition$(p) = "Cell no. " + STR$(p / 2) + " reached a voltage potential outside the specified range at " + STR$(count) + " seconds."
             END IF
           ELSEIF VOLTAGE(p) < 61 OR VOLTAGE(p) > 59 THEN   'CHECKS THE VOLTAGE ACROSSE CELLS
                    voltcount(p) = 0
         END IF
       NEXT p

'THIS LOOPS CHECK FOR THE PASSAGE OF FIFTEEN MINUTES (900 SECONDS).  WHEN THIS
'    OCCURS, THE CURRENT SHUNT VOLTAGE VALUES ARE STORED IN THE FILE "PLOT.DAT"
'    TO ALLOW PLOTTING OF THE DATA AFTER COMPLETION OF THE TEST:

       IF finish - first < 2 OR (finishcount - firstcount > 899 AND finishcount - firstcount < 901) THEN 'CHECKS FOR FIFTEEN MINUTE INTERVALS
              PRINT #2, USING "#####,   "; finish - first;
              FOR q = 1 TO 13 STEP 2
                     PRINT #2, USING "#.###,  "; VOLTAGE(q); 'PRINTS TO FILE PLOT.DAT THE CURRENT AND TIME ELAPSED
              NEXT q
                     PRINT #2, USING "#.###  "; VOLTAGE(15); 'PRINTS TO FILE PLOT.DAT THE CURRENT AND TIME ELAPSED
              PRINT #2,
              firstcount = finishcount
              LOCATE 20, 1
       END IF

       start = finish      'RESETS THE TIMER

       GOTO b

END IF

       GOTO b

'THESE TWO LINES SET ALL DIGITAL OUTPUT CHANNELS TO ZERO, TO SHUT DOWN THE
'    EQUIPMENT AND END THE TEST:

c:   dat = 0
       CALL DigitalOutput(dat)  'ACCESSES THE SUBROUTINE TO CONTROL THE DIGITAL OUTPUTS

'THIS LINE PRINTS THE TEST DESCRIPTION TO FILE "RESULTS.DAT":

              PRINT #1, descrip$

'THESE LINES OUTPUT THE FINAL DATA TO DISK.  THE LOOPS RUNS THROUGH THE
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'    INDEXES FOR THE CHANNELS OF THE SHUNT RESISTORS:

             PRINT #1, "ENDING TIME: ", TIME$
       FOR r = 1 TO 15 STEP 2
         PRINT #1, USING "For cell no. #, the total charge is ##### coulombs"; (r + 1) / 2; CHARGE(r)'PRINTS THE TOTAL CHARGE TO THE FILE RESULTS.DAT
         PRINT #1, condition$(r + 1)
       NEXT r

'THESE TWO LINES CLOSE THE DATA FILES RESULTS.DAT AND PLOT.DAT

CLOSE #1
CLOSE #2

END  'ENDS THE PROGRAM

'**************************************************  SUBROUTINES  *********************************************

'*********************************  ADCONV   *********************************
'THIS SUBROUTINE ACCESSES THE TWO PCL-711 INTERFACE CARDS' A/D CONVERTER TO
'  OBTAIN THE VOLTAGES TO DETERMINE THE CHARGE THROUGH THE PERMEABILITY CELLS
'  AND ALSO ACQUIRES THE VOLTAGE ACROSS THE CELLS SO THAT IT CAN BE CHECKED
'  FOR CONFORMANCE TO THE TEST SPECIFICATION


'*******************************  BREAKOUT   *********************************
'THIS SUBROUTINE ALLOWS THE OPERATOR TO END THE PROGRAM IN THE CASE OF A
'  MALFUNCTION


'*****************************  DIGITALOUTPUT  *******************************
'THIS SUBROUTINE TRIGGERS THE DIGITAL OUTPUT, WHEN NECSSARY, IN THE PCL-711
'  CARD

SUB ADConv (VOLTAGE(), finish, start)

'THIS LINE DIMENSIONS THE VARIABLES NEEDED TO ACCESS THE PCL-711 CARD

DIM ary1%(1000), ary2%(1000), dat%(16), param%(60), param2%(60), corremp(8)

SHUNT = 3    'OHMS RESISTANCE OF SHUNT FOR MEASURING CURRENT

'THESE LINES SET THE VALUES FOR THE EMPIRICALLY DERIVED VOLTAGE DIVIDER
'    CORRECTION FACTOR:

corremp(1) = 1!
corremp(2) = 1!
corremp(3) = 1!
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corremp(4) = 1!
corremp(5) = 1!
corremp(6) = 1!
corremp(7) = 1!
corremp(8) = 1!

'THERE ARE TWO SEPARATE SETS OF STATEMENTS: ONE TAKES DATA FROM THE FIRST
'    CARD FOR CELLS ONE THROUGH FOUR AND THE OTHER TAKES DATA FROM THE
'    SECOND CARD FOR CELLS FIVE THROUGH EIGHT.  EACH SET RETURNS THE
'    APPROPRIATE CALCULATED VALUES FOR VOLTAGE AS ACQUIRED FROM THE PCL-711:

'THESE LINES SET THE PARAMETERS NEEDED TO ACCESS THE FIRST PCL-711:

param%(0) = 0                  ' Board number
param%(1) = &H200               ' Base I/O address
param%(4) = 2                   ' IRQ level : IRQ2
param%(5) = 50                  ' Pacer rate = 2M / (50 * 100) = 400 Hz
param%(6) = 100                 '
param%(7) = 0                   ' Trigger mode, 0 : pacer trigger
param%(8) = 0                   ' Non-cyclic
param%(10) = VARPTR(dat%(0))    ' Offset of A/D data buffer A
param%(11) = VARSEG(dat%(0))    ' Segment of A/D data buffer A
param%(12) = 0                  ' Data buffer B address, if not used,
param%(13) = 0                  ' must set to 0.
param%(14) = 50                 ' A/D conversion number
param%(15) = 0                  ' A/D conversion start channel
param%(16) = 7                  ' A/D conversion stop channel
param%(17) = 0                  ' Overall gain code, 0 : +/- 5V

' PARAM%(45) : Error Code
' PARAM%(46) : Return Value 0
' PARAM%(47) : Return Value 1

FUN% = 3                        ' FUNCTION 3 FOR HARDWARE INITIALIZATION

'THIS LINE CALLS THE PCL-711 DRIVER AND INITIALIZES IT:

CALL PCL711(FUN%, SEG param%(0))

FUN% = 100                      'FUNCTION 100 FOR A/D INITIALIZATION

'THIS LINE CALLS THE PCL-711 DRIVER AND INITIALIZES A/D CONVERSION:

CALL PCL711(FUN%, SEG param%(0))

'THIS LINE SETS FUNCTION 105 FOR PACER TRIGGER A/D CONVERSION WITH INTERUPT DATA
'    TRANSFER:
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FUN% = 105

'THIS LINE CALLS THE PCL-711 DRIVER AND SETS THE PACER TO TRIGGER A/D
'    CONVERSION WITH INTERUPT DATA TRANSFER:

CALL PCL711(FUN%, SEG param%(0))

'THIS LINE SETS FUNCTION 106 TO CHECK INTERRUPT STATUS

FUN% = 106

'THIS LINE CALLS THE PCL-711 DRIVER AND CHECKS INTERRUPT STATUS

CALL PCL711(FUN%, SEG param%(0))   ' Func 106: Check interrupt status

'THIS LOOP READS THE VOLTAGES FROM THE FIRST PCL-711 CARD AND CALCULATES THE
'    CURRENT THROUGH THE CELL AND VOLTAGE ACROSS THE CELL:

FOR s = 0 TO 7 STEP 2

  'THIS LINE CALLS THE PCL-711 DRIVER TO READ THE SHUNT AND DIVIDER VOLTAGES:

       CALL PCL711(FUN%, SEG dat%(0), SEG ary1%(0), SEG ary2%(0), ER%)

  'THIS LINE TAKES THE VOLTAGE ACROSS SHUNT AND RETURNS THE CURRENT IN AMPS
  '    AND MULTIPLIES BY TIME ELAPSED SINCE THE LAST READING TO CALCULATE THE
  '    ACCUMULATED CHARGE ACROSS THE SPECIMEN:

       VOLTAGE(s + 1) = ((finish - start) * ((dat%(s) * .00244) + (-5))) / SHUNT

  'THIS LOOP SETS THE CORRECTION FACTOR TO ADJUST FOR VARIATIIONS IN THE
  '    VOLTAGE DIVIDER RESISTORS:

       IF s + 1 = 1 THEN
           corr = 26.357 * corremp(1)
       ELSEIF s + 1 = 3 THEN
           corr = 26.046 * corremp(2)
       ELSEIF s + 1 = 5 THEN
           corr = 26.395 * corremp(3)
       ELSEIF s + 1 = 7 THEN
           corr = 26.067 * corremp(4)
       END IF

  'THIS LINE TAKES THE VOLTAGE ACROSS THE SMALLER DIVIDER RESISTOR AND
  '    MULTIPLIES BY THE CORRECTION FACTOR TO CALCULATE THE VOLTAGE ACROSS THE
  '    SPECIMEN CELL:
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      VOLTAGE(s + 2) = ((dat%(s + 1) * .00244) + (-5)) * corr

NEXT s

'THESE LINES SET THE PARAMETERS NEEDED TO ACCESS THE SECOND PCL-711

  param2%(0) = 1                  ' Board number
  param2%(1) = &H220              ' Base I/O address
  param2%(4) = 2                  ' IRQ level : IRQ2
  param2%(5) = 50                 ' Pacer rate = 2M / (50 * 100) = 400 Hz
  param2%(6) = 100                ' A/D initialization
  param2%(7) = 0                  ' Trigger mode, 0 : pacer trigger
  param2%(8) = 0                  ' Non-cyclic
  param2%(10) = VARPTR(dat%(0))   ' Offset of A/D data buffer A
  param2%(11) = VARSEG(dat%(0))   ' Segment of A/D data buffer A
  param2%(12) = 0                 ' Data buffer B address, if not used,
  param2%(13) = 0                 ' must set to 0.
  param2%(14) = 50                ' A/D conversion number
  param2%(15) = 0                 ' A/D conversion start channel
  param2%(16) = 7                 ' A/D conversion stop channel
  param2%(17) = 0                 ' Overall gain code, 0 : +/- 5V

FUN% = 3                       'FUNCTION 3 FOR HARDWARE INITIALIZATION

'THIS LINE CALLS THE PCL-711 DRIVER AND INITIALIZES IT:

CALL PCL711(FUN%, SEG param2%(0))

FUN% = 100                     'FUNCTION 100 FOR A/D INITIALIZATION

'THIS LINE CALLS THE PCL-711 DRIVER AND INITIALIZES A/D CONVERSION:

CALL PCL711(FUN%, SEG param2%(0))

FUN% = 105                     ' FUNCTION 105

'THIS LINE SETS FUNCTION 105: PACER TRIGGER A/D CONVERSION WITH INTERUPT DATA
'    TRANSFER:

CALL PCL711(FUN%, SEG param2%(0))

'THIS LINE SETS FUNCTION 106 TO CHECK INTERRUPT STATUS

FUN% = 106

'THIS LINE CALLS THE PCL-711 DRIVER AND CHECKS INTERRUPT STATUS:
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CALL PCL711(FUN%, SEG param2%(0))

'THIS LOOP READS THE VOLTAGES FROM THE SECOND PCL-711 CARD AND CALCULATES THE
'    CURRENT THROUGH THE CELL AND VOLTAGE ACROSS THE CELL:

FOR t = 0 TO 7 STEP 2

  'THIS LINE CALLS THE PCL-711 DRIVER TO READ THE SHUNT AND DIVIDER VOLTAGES:

       CALL PCL711(FUN%, SEG dat%(0), SEG ary1%(0), SEG ary2%(0), ER%)

  'THIS LINE TAKES THE VOLTAGE ACROSS SHUNT AND RETURNS THE CURRENT IN AMPS
  '    AND MULTIPLIES BY TIME ELAPSED SINCE THE LAST READING TO CALCULATE THE
  '    ACCUMULATED CHARGE ACROSS THE SPECIMEN:

       VOLTAGE(t + 9) = ((finish - start) * ((dat%(t) * .00244) + (-5))) / SHUNT

  'THIS LOOP SETS THE CORRECTION FACTOR TO ADJUST FOR VARIATIIONS IN THE
  '    VOLTAGE DIVIDER RESISTORS:

       IF t + 1 = 1 THEN
           corr = 26.26 * corremp(5)
       ELSEIF t + 1 = 3 THEN
           corr = 26.02 * corremp(6)
       ELSEIF t + 1 = 5 THEN
           corr = 26.076 * corremp(7)
       ELSEIF t + 1 = 7 THEN
           corr = 26.352 * corremp(8)
       END IF

  'THIS LINE TAKES THE VOLTAGE ACROSS THE SMALLER DIVIDER RESISTOR AND
  '    MULTIPLIES BY THE CORRECTION FACTOR TO CALCULATE THE VOLTAGE ACROSS
  '    THE SPECIMEN CELL:

       VOLTAGE(t + 10) = ((dat%(t + 1) * .00244) + (-5)) * corr

NEXT t

END SUB

SUB BreakOut (CHARGE(), finish, first, state$)

IF state$ = "stop" THEN

'THESE TWO LINES ALLOW THE OPERATOR TO CONFIRM THE THE TERMINATION OF THE TEST:
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        LOCATE 20, 1
        PRINT "You have indicated that you wish to end the test."
e:    INPUT "Are you sure? ", choice$

'THIS LOOP VALIDATES THE VALUE OF CHOICE$:

        IF choice$ <> "Y" AND choice$ <> "y" AND choice$ <> "N" AND choice$ <> "n" THEN
                PRINT "That is not an acceptable input. Please try again."
                GOTO e
        END IF

'THIS LOOP ACTS ON THE VALUE OF CHOICE$:

        IF choice$ = "Y" OR choice$ = "y" THEN
                dat = 0
                CALL DigitalOutput(dat)

'THESE LINES OUTPUT THE CURRENT DATA TO FILE IF THE TEST IS ENDED PREMATURELY:

                PRINT #1, descrip$
                PRINT #1, "DATE OF TEST: ", DATE$
                PRINT #1, "The test was halted at "; TIME$; " by the operator."
                PRINT #1, USING "The number of seconds elapsed was ###### seconds (#.### hours)."; finish - first; (finish - first) / 3600
                FOR z = 1 TO 11 STEP 2
                        z1 = (z + 1) / 2
                        PRINT #1, USING "The charge on cell no. # was #####.# coulombs."; z1; CHARGE(z)
                NEXT z
                END
        ELSEIF choice$ = "N" OR choice$ = "n" THEN
                state$ = ""
                CLS
        END IF

END IF

END SUB

SUB DigitalOutput (dat)

'THIS LINE INITIALIZES THE FOLLOWING ARRAYS:

DIM dat%(100), param%(60)

'THESE LINES SET THE PARAMETERS NEEDED TO ACCESS THE FIRST PCL-711 FOR DIGITAL
'     OUTPUT:

param%(0) = 0                    ' Board number
```


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```
param%(1) = &H200             ' Base I/O address
param%(33) = VARPTR(dat%(0))  ' Offset of digital output data buffer A
param%(34) = VARSEG(dat%(0))  ' Segment of digital output data buffer A
param%(35) = 0                ' Data buffer B address, if not used,
param%(36) = 0                ' must set to 0.
param%(37) = 1                ' Digital output number
param%(38) = 0                ' Digital output port

'FUNCTION 3 INITIALIZES THE PCL-711 DRIVER:

  FUN% = 3

'THIS LINE INITIALIZES THE PCL-711 DRIVER:

  CALL PCL711(FUN%, SEG param%(0))

  FUN% = 28                     ' FUNCTION 28 INITIALIZES THE DIGITAL OUTPUT

'THIS LINE INITIALIZES THE DIGITAL OUTPUT

  CALL PCL711(FUN%, SEG param%(0))

  dat%(0) = dat

'FUNCTION 29 SETS THE DRIVER FOR "N" TIMES OF DIGITAL OUTPUT:

  FUN% = 29

'THIS LINE SENDS THE VALUE OF dat%(0) TO THE DRIVER:

  CALL PCL711(FUN%, SEG param%(0))

END SUB

SUB to12 (twelvehourtime$)
'THIS LINE ACCESSES THE BASIC TIME FUNCTION AND STORES THE CURRENT TIME IN
'    THE VARIABLE t$:
  t$ = TIME$
'THIS LINE READS THE LEFTMOST NUMERIC CHARACTERS FROM t$ (IN THE FORMAT
'    HH:MM:SS) INTO THE VARIABLE hr AND DISCARDS EVERYTHING AFTER THE FIRST
'    COLON.  IT THEN CONVERTS THE STRING VALUE TO A NUMBER (THE HOUR OF THE
'    TIME):
  hr = VAL(t$)
'THIS LINE DETERMINES WHETHER THE TIME IS AM OR PM AND THEN SETS ampm$
'    APPROPRIATELY:
    IF hr < 12 THEN ampm$ = " am" ELSE ampm$ = " pm"
'THIS LINE DETERMINES WHETHER THE TIME NEEDS TO BE CONVERTED TO A TWELVE HOUR
```

```
'    SYSTEM AND CONVERTS IT AS NECESSARY:
    IF hr > 12 THEN hr = hr - 12
'THIS LINE GENERATES THE TWELVE HOUR TIME:
  twelvehourtime$ = STR$(hr) + RIGHT$(t$, 6) + ampm$
END SUB
```


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Appendix B

Standard Method of Test for

Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration

AASHTO Designation: T 277-96 (2000)
ASTM Designation: C 1202-94

1. SCOPE

1.1. This test method covers the determination of the electrical conductance of concrete to provide a rapid indication of its resistance to the penetration of chloride ions. This test method is applicable to types of concrete where correlations have been established between this test procedure and long-term chloride ponding procedures such as those described in T 259. Examples of such correlations are discussed in References (1–5).[1]

1.2. The values stated in SI units are to be regarded as the standard.

1.3. *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- T 23, Making and Curing Concrete Test Specimens in the Field
- T 24, Obtaining and Testing Drilled Cores and Sawed Beams of Concrete
- T 126, Making and Curing Concrete Test Specimens in the Laboratory
- T 259, Resistance of Concrete to Chloride Ion Penetration

2.2. *ASTM Standard*:

- C 670, Practice for Preparing Precision and Bias Statements for Test Methods for Construction Purposes

3. SUMMARY OF TEST METHOD

3.1. This test method consists of monitoring the amount of electrical current passing through 50-mm (2-in.) thick slices of 100-mm (4-in.) nominal diameter cores or cylinders during a six-hour period. A potential difference of 60 V dc is maintained across the ends of the specimen, one of which is immersed in a sodium chloride solution, the other in a sodium hydroxide solution. The total charge passed, in coulombs, has been found to be related to the resistance of the specimen to chloride ion penetration.

4. SIGNIFICANCE AND USE

4.1. This test method covers the laboratory evaluation of the electrical conductance of concrete samples to provide a rapid indication of their resistance to chloride ion penetration. In most cases the electrical conductance results have shown good correlation with chloride ponding tests, such as T 259, on companion slabs cast from the same concrete mixtures (References 1–5).

4.2. This test method is suitable for evaluation of materials and material proportions for design purposes and research and development.

4.3. The numerical results (total charge passed, in coulombs) from this test method must be used with caution, especially in applications such as quality control and acceptance testing. The qualitative terms in the right-hand column of Table 1 should be used in most cases unless otherwise noted by the specifying agency.

Table 1—Chloride Ion Penetrability Based on Charge Passed

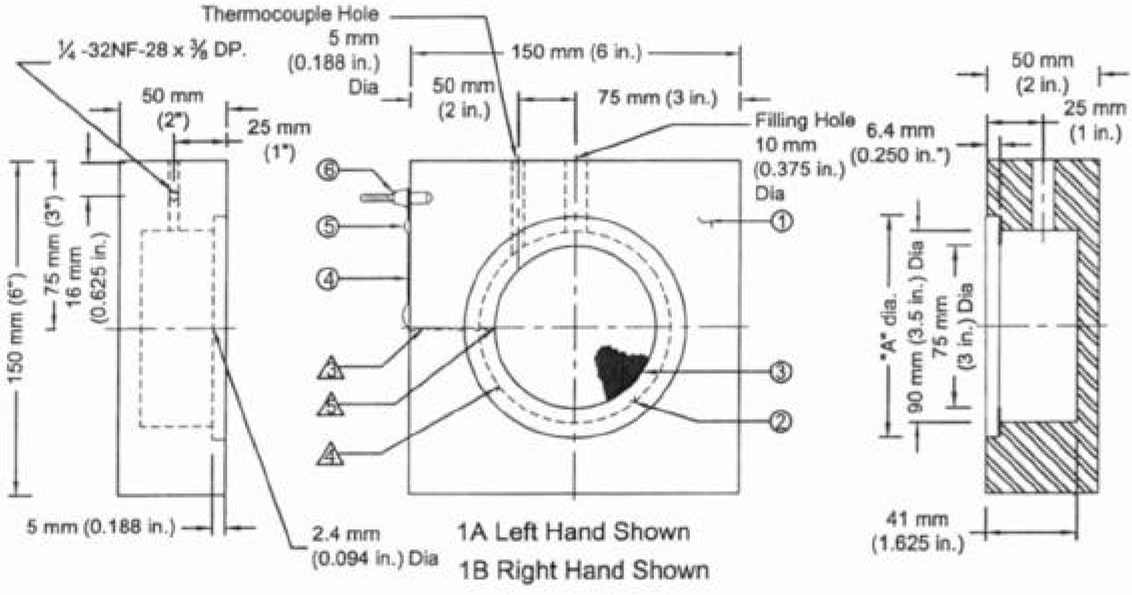
Charge Passed (Coulombs)	Chloride Ion Penetrability
>4000	High
>2000–4000	Moderate
>1000–2000	Low
100–1000	Very low
<100	Negligible

4.4. Care should be taken in interpreting results of this test when it is used on surface-treated concretes, for example, concretes treated with penetrating sealers. The results from this test on some such concretes indicate low resistance to chloride ion penetration, while 90-day chloride ponding tests on companion slabs show a higher resistance.

4.5. The details of the test method apply to 100-mm (4 in.) nominal diameter specimens. This includes specimens with actual diameters ranging from 95 mm (3.75 in.) to 100 mm (4 in.). Other specimen diameters may be tested with appropriate changes in the applied voltage cell design. (See Section 7.5 and Figure 1.)

4.5.1. For specimen diameters other than 95 mm (3.75 in.), the test result value for total charge passed must be adjusted following the procedure in Section 11.2. For specimens with diameters less than 95 mm (3.75 in.), particular care must be taken in coating and mounting the specimens to ensure that the conductive solutions are able to contact the entire end areas during the test.

4.6. Sample age may have significant effects on the test results, depending on the type of concrete and the curing procedure. Most concretes, if properly cured, become progressively and significantly less permeable with time.



△ Notes: 1. Diameter "A" should be 3.2 mm (0.125 in.) larger than outside diameter of specimen.
2. Not to scale
3. Seal Wire in hole with Silicone Rubber Caulk.
4. Screen soldered between Shims.
5. Solder Wire to Brass Shim.
6. Polymethylmethacrylate, e.g., Plexiglas

Equivalents

Item	Qty.	Nomenclature	Specification
1.A 1.B	1 1	Cell Block End	DMMA Sheet
2	4	Shim, Brass	0.5 mm (0.02 in.) THK
3	2	Screen, Brass	0.85 mm (No. 20) mesh. "a" diameter
4	2	Wire, Copper	14, Solid Nylclad
5	2	Terminal	12-10-1/4
6	2	Banana Plug	6.4 mm (0.25 in.) male insulated

Figure 1—Applied Voltage Cell (Construction Drawing)

5. INTERFERENCES

5.1. This test method can produce misleading results when calcium nitrite has been admixed into a concrete. The results from this test on some such concretes indicate higher coulomb values, that is, lower resistance to chloride ion penetration, than from tests on identical concrete mixtures (controls) without calcium nitrite. However, long-term chloride ponding tests indicate the concretes with calcium nitrite were at least as resistant to chloride ion penetration as the control mixtures.

Note 1—Other admixtures might affect results of this test similarly. Long-term ponding tests are recommended if an admixture effect is suspected.

5.2. Since the test results are a function of the electrical resistance of the specimen, the presence of reinforcing steel or other embedded electrically conductive materials may have a significant effect. The test is not valid for specimens containing reinforcing steel positioned longitudinally, that is, providing a continuous electrical path between the two ends of the specimen.

6. APPARATUS

6.1. *Vacuum Saturation Apparatus*: (See Figure 2 for example.)

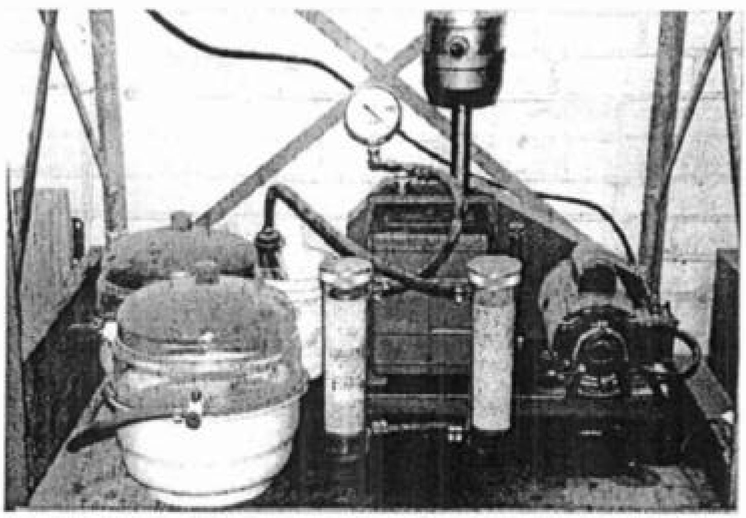


Figure 2—Vacuum Saturation Apparatus

6.1.1. *Separatory Funnel*—or other sealable, bottom-draining container with a minimum capacity of 500 mL.

6.1.2. *Beaker* (1000 mL or larger) or other container—Capable of holding concrete specimen(s) and water and of fitting into vacuum desiccator. (See Section 6.1.3.)

6.1.3. *Vacuum Desiccator*—250-mm (9.8-in.) inside diameter or larger. Desiccator must allow two hose connections, through rubber stopper and sleeve or through rubber stopper only. Each connection must be equipped with a stopcock.

6.1.4. *Vacuum Pump*—Capable of maintaining a pressure of less than 133 Pa (1 mm Hg) in dessicator.

Note 2—Since vacuum will be drawn over water, pump should be protected with a water trap, or pump oil should be changed after each operation.

6.1.5. *Vacuum Gage or Manometer*—Accurate to ±66 Pa (±0.5 mm Hg) over range 0 to 1330 Pa (0 to 10 mm Hg) pressure.

6.2. *Coating Apparatus and Materials*:

6.2.1. *Coating*—Rapid setting, electrically nonconductive, capable of sealing side surface of concrete cores.

6.2.2. *Balance or Scale, Paper Cups, Wooden Spatulas, and Disposable Brushes*—For mixing and applying coating.

6.3. *Specimen-Sizing Equipment* (not required if samples are cast to final specimen size).

6.3.1. *Movable Bed Water-Cooled Diamond Saw or Silicon Carbide Saw*.

7. REAGENTS, MATERIALS, AND TEST CELL

7.1. *Specimen-Cell Sealant*—Capable of sealing concrete to poly methyl methacrylate, for example, Plexiglas, against water and dilute sodium hydroxide and sodium chloride solutions at temperatures up to 90°C (200°F); examples include RTV silicone rubbers, silicone rubber caulkings, other synthetic rubber sealants, silicone greases, and rubber gaskets.

7.2. *Sodium Chloride Solution*—3.0 percent by mass (reagent grade) in distilled water.

7.3. *Sodium Hydroxide Solution*—0.3 Normal (reagent grade) in distilled water.

7.4. *Filter Papers*—90 mm (No. 2) diameter (not required if rubber gasket is used for sealant (Section 7.1) or if sealant can be applied without overflowing from shim onto mesh).

7.5. *Applied Voltage Cell (Figures 1 and 3)*—Two symmetric poly methyl methacrylate chambers, each containing electrically conductive mesh and external connectors. One design in common use is shown in Figures 1 and 3. However, other designs are acceptable, provided that overall dimensions (including dimensions of the fluid reservoir) are the same as shown in Figure 1 and width of the screen and shims are as shown.

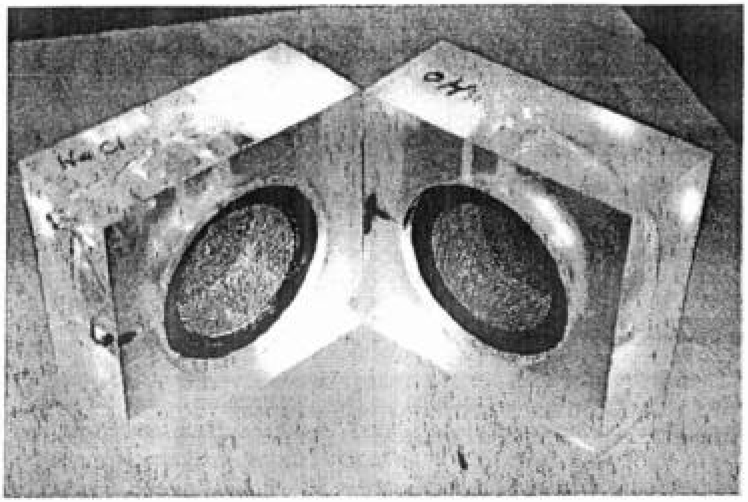


Figure 3—Applied Voltage Cell-Face View

7.6. *Thermocouple Wire and Readout Device (optional)*—0 to 120°C (30 to 250°F) range.

7.7. *Voltage Application and Data Readout Apparatus*—Capable of holding 60 ± 0.1 V dc across applied voltage cell over entire range of currents and of displaying voltage accurate to ±0.1 V and current to ±1 mA. Apparatus listed in Sections 7.7.1 through 7.7.5 is a possible system meeting this requirement.

7.7.1. *Voltmeter*—Digital (DVM), 3 digit, minimum 0-99.9 V range, rated accuracy ±0.1 percent.

7.7.2. *Voltmeter*—Digital (DVM), $4^1/_2$ digit, 0-200 mV range, rated accuracy ±0.1 percent.

7.7.3. *Shunt Resistor*—100 mV, 10A rating, tolerance ±0.1 percent. Alternatively, a 0.01 Ω resistor, tolerance ±0.1 percent, may be used, but care must be taken to establish very low resistance connections.

7.7.4. *Constant Voltage Power Supply*—0-80 V dc, 0-2 A, capable of holding voltage constant at 60 ± 0.1 V over entire range of currents.

7.7.5. *Cable*—Two conductor, 1.6 mm (No. 14), insulated, 600 V.

8. TEST SPECIMENS

8.1. Sample preparation and selection depends on the purpose of the test. For evaluation of materials or their proportions, samples may be (a) cores from test slabs or from large diameter cylinders or (b) 100-mm (4-in.) diameter cast cylinders. For evaluation of structures, samples may be (a) cores from the structure or (b) 100-mm (4-in.) diameter cylinders cast and cured at the field site. Coring shall be done with a drilling rig equipped with a 100-mm (4-in.) diameter diamond-dressed core bit. Select and core samples following procedures in T 24. Cylinders cast in the laboratory shall be prepared following procedures in T 126. When cylinders are cast in the field to evaluate a structure, care must be taken that the cylinders receive the same treatment as the structure, for example, similar degree of consolidation, curing, and temperature history during curing.

Note 3—The maximum allowable aggregate size has not been established for this test. Users have indicated that test repeatability is satisfactory on specimens from the same concrete batch for aggregates up to 25.0-mm (1-in.) nominal maximum size.

8.2. Transport the cores or field-cured cylinders to the laboratory in sealed (tied) plastic bags. If specimens must be shipped, they should be packed to be properly protected from freezing and damage in transit or storage.

8.3. Using the water-cooled diamond saw or silicon carbide saw, cut a 50 ± 3 mm (2 ± 0.125 in.) slice from the top of the core or cylinder, with the cut parallel to the top of the core. This slice will be the test specimen. Use a belt sander to remove any burrs on the end of the specimen.

8.4. Special processing is necessary for core samples where the surface has been modified, for example, by texturing or by applying curing compounds, sealers, or other surface treatments, and where the intent of the test is not to include the effect of the modifications. In those cases, the modified portion of the core shall be removed and the subsequent 50 ± 3 mm (2 ± 0.125 in.) slice shall be used for the test.

9. CONDITIONING

9.1. Vigorously boil a liter or more of tapwater in a large sealable container. Remove container from heat, cap tightly, and allow water to cool to ambient temperature.

9.2. Allow specimen prepared in Section 8 to surface dry in air for at least one hour. Prepare approximately 10 g (0.5 oz) of rapid setting coating and brush onto the side surface of specimen. Place the sample on a suitable support while coating to ensure complete coating of sides. Allow coating to cure according to the manufacturer's instructions.

9.3. The coating should be allowed to cure until it is no longer sticky to the touch. Fill any apparent holes in the coating and allow additional curing time, as necessary. Place specimen in beaker or other container (Section 6.1.2), then place container in vacuum desiccator. Alternatively, place specimen directly in vacuum desiccator. Both end faces of specimen must be exposed. Seal desiccator and start vacuum pump. Pressure should decrease to less than 133 Pa (1 mm Hg) within a few minutes. Maintain vacuum for three hours.

9.4. Fill separatory funnel or other container (Section 6.1.1) with the de-aerated water prepared in Section 9.1. With vacuum pump still running, open water stopcock and drain sufficient water into beaker or container to cover specimen. (Do not allow air to enter desiccator through this stopcock.)

9.5. Close water stopcock and allow vacuum pump to run for one additional hour.

9.6. Close vacuum line stopcock, then turn off pump. (Change pump oil if a water trap is not being used.) Turn vacuum line stopcock to allow air to re-enter desiccator.

9.7. Soak specimen under water (the water used in Sections 9.4 through 9.6) in the beaker for 18 ± 2 hours.

10. PROCEDURE

10.1. Remove specimen from water, blot off excess water, and transfer specimen to a sealed can or other container, which will maintain the specimen in 95 percent or higher relative humidity.

10.2. Specimen mounting (all sealants other than rubber gaskets: use 10.2.2 or 10.2.3, as appropriate):

10.2.1. If using two-part specimen-cell sealant, prepare approximately 20 to 40 g (0.7 to 1.4 oz).

10.2.2. *Low-Viscosity, Specimen-Cell Sealant*—If filter paper is necessary, center filter paper over one screen of the applied voltage cell. Trowel sealant over brass shims adjacent to applied voltage cell body. Carefully remove filter paper. Press specimen onto screen; remove or smooth excess sealant that has flowed out of specimen-cell boundary.

10.2.3. *High-Viscosity, Specimen-Cell Sealant*—Set specimen onto screen. Apply sealant around specimen-cell boundary.

10.2.4. Cover exposed face of specimen with an impermeable material such as rubber or plastic sheeting. Place rubber stopper in cell filling hole to restrict moisture movement. Allow sealant to cure per manufacturer's instructions.

10.2.5. Repeat steps in Sections 10.2.2 (or 10.2.3) and 10.2.4 on second half of cell. (Specimen in applied voltage cell now appears as shown in Figure 4.)

10.3. *Specimen Mounting* (Rubber Gasket Alternative)—Place a 100-mm (4-in.) outside diameter by 75-mm (3-in.) inside diameter by 6-mm (0.25-in.) circular vulcanized rubber gasket in each half of the test cell. Insert sample and clamp the two halves of the test cell together to seal.

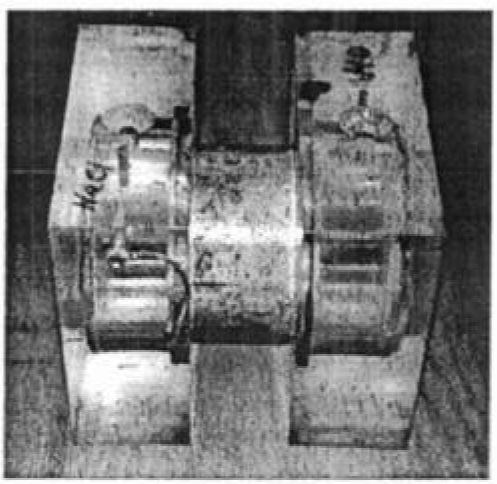


Figure 4—Specimen Ready for Test

10.4. Fill the side of the cell containing the top surface of the specimen with 3.0 percent NaCl solution. (That side of the cell will be connected to the negative terminal of the power supply in Section 10.5.) Fill the other side of the cell (which will be connected to the positive terminal of the power supply) with 0.3 Normal NaOH solution.

10.5. Attach lead wires to cell banana posts. Make electrical connections to voltage application and data readout apparatus as appropriate: for example, for systems listed in Sections 7.7.1 through 7.7.5, connect as shown in Figure 5. Turn power supply on, set to 60.0 ± 0.1 V, and record initial current reading. Temperatures of the specimen, applied voltage cell, and solutions shall be 20 to 25°C (68 to 77°F) at the time the test is initiated, that is, when the power supply is turned on.

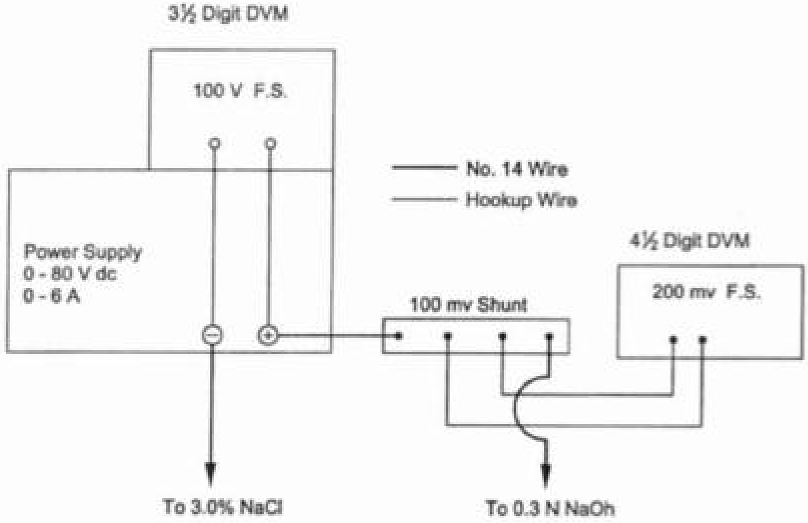


Figure 5—Electrical Block Diagram (example)

10.6. During the test, the air temperature around the specimens shall be maintained in the range of 20 to 25°C (68 to 77°F).

10.7. Read and record current at least every 30 minutes. If a voltmeter is being used in combination with a shunt resistor for the current reading (Figure 5), use appropriate scale factors to convert voltage reading to amperes. Each half of the test cell must remain filled with the appropriate solution for the entire period of the test.

Note 4—During the test, the temperature of the solutions should not be allowed to exceed 90°C (190°F) in order to avoid damage to the cell and to avoid boiling off the solutions. Although it is not a requirement of the method, the temperature of the solutions can be monitored with thermocouples installed through the 3-mm (0.125-in.) venthole in the top of the cell. High temperatures occur only for highly penetrable concretes. If a test of a 50-mm (2-in.) thick specimen is terminated because of high temperatures, this should be noted in the report, along with the time of termination, and the concrete rated as having very high chloride ion penetrability. (See Section 12.1.9.)

10.8. Terminate test after six hours, except as discussed in Note 4.

10.9. Remove specimen. Rinse cell thoroughly in tap water; strip out and discard residual sealant.

11. CALCULATION AND INTERPRETATION OF RESULTS

11.1. Plot current (in amperes) versus time (in seconds). Draw a smooth curve through the data, and integrate the area underneath the curve in order to obtain the ampere-seconds, or coulombs, of charge passed during the six-hour test period. (See Note 5.) Alternatively, use automatic data processing equipment to perform the integration during or after the test and to display the coulomb value. The total charge passed is a measure of the electrical conductance of the concrete during the period of the test.

Note 5—*Sample Calculation*—If the current is recorded at 30-minute intervals, the following formula, based on the trapezoidal rule, can be used with an electronic calculator to perform the integration:

$$Q = 900\,(I_0 + 2I_{30} + 2I_{60} \cdots + 2I_{300} + 2I_{330} + I_{360}) \qquad (1)$$

where:

Q = charge passed (coulombs),

I_0 = current (amperes) immediately after voltage is applied, and

I_t = current (amperes) at t min after voltage is applied.

11.2. If the specimen diameter is other than 95 mm (3.75 in.), the value for total charge passed established in Section 11.1 must be adjusted. The adjustment is made by multiplying the value established in Section 11.1 by the ratio of the cross-sectional areas of the standard and the actual specimens. That is:

$$Q_s = Q_x \times \left(\frac{3.75}{x}\right)^2 \qquad (2)$$

where:

Q_s = charge passed (coulombs) through a 95-mm (3.75-in.) diameter specimen,

Q_x = charge passed (coulombs) through x mm (in.) diameter specimen, and

x = diameter mm (in.) of the nonstandard specimen.

11.3. Use Table 1 to evaluate the test results. These values were developed from data on slices of cores taken from laboratory slabs prepared from various types of concretes.

11.3.1. Factors which are known to affect chloride ion penetration include: water-cement ratio, the presence of polymeric admixtures, sample age, air-void system, aggregate type, degree of consolidation, and type of curing.

12. REPORT

12.1. Report the following, if known:

12.1.1. Source of core or cylinder, in terms of the particular location the core or cylinder represents.

12.1.2. Identification number of core or cylinder and specimen.

12.1.3. Location of specimen within core or cylinder.

12.1.4. Type of concrete, including binder type, water–cement ratio, and other relevant data supplied with samples.

12.1.5. Description of specimen, including presence and location of reinforcing steel, presence and thickness of overlay, and presence and thickness of surface treatment.

12.1.6. Curing history of specimen.

12.1.7. Unusual specimen preparation, for example, removal of surface treatment.

12.1.8. Test results, reported as the total charge passed over the test period (adjusted per Section 11.2)., and

12.1.9. The qualitative chloride ion penetrability equivalent to the calculated charge passed (from Table 1).

13. PRECISION AND BIAS[2]

13.1. *Precision*:

13.1.1. *Single-Operator Precision*—The single operator coefficient of variation of a single test result has been found to be 12.3 percent (Note 6). Therefore, the results of two properly conducted tests by the same operator on concrete samples from the same batch and of the same diameter should not differ by more than 35 percent (Note 6).

13.1.2. *Multilaboratory Precision*—The multilaboratory coefficient of variation of a single test result has been found to be 18.0 percent (Note 6). Therefore results of two properly conducted tests in different laboratories on the same material should not differ by more than 51 percent (Note 6). The average of three test results in two different laboratories should not differ by more than 29 percent (Note 7).

Note 6—These numbers represent, respectively, the (1s percent) and (d2s percent) limits as described in ASTM C 670. The precision statements are based on the variations in tests on three different concretes, each tested in triplicate in 11 laboratories. All specimens had the same actual diameters, but lengths varied within the range 50 ± 3 mm (2 ± 0.125 in.).

Note 7—Although the test method does not require the reporting of more than one test result, testing of replicate specimens is usually desirable. The precision statement for the averages of three results is given since laboratories frequently will run this number of specimens. The percentage cited represents the (d2s percent) limit divided by the square root of 3.

13.2. *Bias*—The procedure of this test method for measuring the resistance of concrete to chloride ion penetration has no bias because the value of this resistance can be defined only in terms of a test method.

14. KEYWORDS

14.1. Chloride content; corrosion; deicing chemicals; resistance-chloride penetration.

15. REFERENCES

15.1. Whiting, D., "Rapid Determination of the Chloride Permeability of Concrete." *Final Report No. FHWA/RD-81/119*. Federal Highway Administration, August 1981, NTIS No. PB 82140724.

15.2. Whiting, D., "Permeability of Selected Concrete." *Permeability of Concrete*, SP-108, American Concrete Institute, Detroit, MI, 1988, pp. 195–222.

15.3. Whiting, D., and Dziedzic, W., "Resistance to Chloride Infiltration of Superplasticized Concrete as Compared with Currently Used Concrete Overlay Systems," *Final Report No. FHWA/OH-89/009*. Construction Technology Laboratories, May 1989.

15.4. Berke, N. S., Pfeifer, D. W., and Weil, T. G., "Protection Against Chloride-Induced Corrosion." *Concrete International*. Vol. 10, No. 12, December 1988, pp. 45–55.

15.5. Ozyildirim, C., and Halstead, W. J., "Use of Admixtures to Attain Low Permeability Concretes," *Final Report No. FHWA/VA-88-R11*. Virginia Transportation Research Council, February 1988, NTIS No. PB 88201264.

[1] The numbers in parentheses refer to the list of references at the end of this standard.
[2] Supporting data have been filed at ASTM headquarters (100 Barr Harbor Drive, Conshohocken, PA 19428-2959) and may be obtained by requesting RR: C-9-1004.

Appendix C

Preparation of Test Solutions

1) Deaerated Distilled Water:

Fill a one liter erlenmyer flask, or one liter beaker with distilled water. Heat to boil and allow to boil for 5 minutes. Transfer to a 4 liter brown colored reagent bottle and allow to cool. Repeat 4 times to fill the 4 liter reagent bottle.

2) 3% Sodium Chloride Solution: (3%NaCl)

This solution should contain 30 grams of sodium chloride per liter of distilled water. Weigh 30 grams of sodium chloride into a 250 ml. beaker. Add about 200 ml. of distilled water. Stir with a magnetic stirrer until all the sodium chloride is dissolved. Pour the contents into a 1 liter volumetric flask. Rinse the empty 250 ml. beaker several times with distilled water and each time pour rinse water into the 1 liter volumetric flask. Finally, add enough distilled water to the 1 liter flask to bring water level up to one liter mark on the neck of the flask. Repeat process 4 times to fill a 4 liter brown colored reagent bottle.

3) 0.01 N Sodium Hydroxide Solution:

This solution should contain 12 grams of sodium hydroxide per liter of distilled water. Weigh 12 grams of sodium hydroxide into 250 ml. beaker. Add about 200 ml. of distilled water. Stir with a magnetic stirrer until all the sodium hydroxide is dissolved. Pour the contents into a 1 liter volumetric flask. Rinse the empty 250 ml. beaker several times with distilled water and each time pour the rinse water into the 1 liter volumetric flask. Finally, add enough distilled water to the 1 liter flask to bring water level up to one liter mark on the neck of the flask. Repeat process 4 times to fill a 4 liter brown colored reagent bottle.

Appendix D

Contents of Included CD-ROM

Winstart.exe - Program to create bootable diskette (Windows 98 Startup Disk) for setup of a new system. The disk contains FDISK.EXE to partition the hard drive and creates a RAM disk to that contains the FORMAT.EXE program. It also loads standard DOS CD-ROM drivers. WINSTART.EXE requires Windows on a machine where the 3.5" floppy drive is designated as "A". There are also instructions on how to partition and format a hard drive, as Acrobat PDF, Word DOC and text files (HD_Setup.txt). It is also available as a self-running executable file viewer, HD_SETUP.EXE and has navigation instructions in the file. Type "HD_SETUP" (quotes are not typed for prompt commands) and enter at the C:>\ prompt (hard drive C root level - accessed by typing "CD\" at any prompt on the C drive; go to the C drive by typing "C:" at any prompt). Note that any computer used to run the permeability apparatus should be dedicated to the task.

FLOPPY - Copy the contents of this folder to a blank formatted floppy disk for computers without a CD-ROM drive. "FLOPPY.BAT" can be run from the CD-ROM if a computer running Windows is not available. Boot with the floppy created with WINSTART.EXE. Then run "CREATE.BAT" on this disk on the permeability computer to set up the minimum required software on the machine.

PERMFILE - This folder contains the QuickBasic software and the program to operate the permeability apparatus. Copy the folder to the hard drive using the batch file "COPY_PT.BAT" (after the drive is formatted). The stand-alone executable program can be run by typing "T" at the C:\> prompt. The source code in QuickBasic is contained in the file "PERM.BAS". QuickBasic runs in the DOS environment, although it should not be necessary to operate the software. The executable would normally be used. QuickBasic need only be used if modifications to the program become necessary.

MANUAL - This folder contains the manual as both Acrobat PDF and Word DOC files (if editing is required). The file for the schematics is provided in CorelDraw 10 CDR format (the program used to create it) and the figures are also given as WMF files.

NC - This folder contains a menu structure program called Disk Commander to facilitate navigation through the tree structure of DOS. The entire folder can be copied to the hard drive (after it's formatted) using the batch file "COPY_NC.BAT". The program can then be run with the "N.BAT" file from the C:>\ prompt by typing "N".

PCL711 - This folder contains the drivers and test files for the PCL-711b I/O card that allows the computer to interface with the cells. It also contains the manual for the card and the PCLD-786 SSR Relay Board as PDF files, as well as a test program for the PCL711b. The Windows drivers are also included, but are not supported by the operational program. Note the files needed to run the program are already in the PERMFILE folder and are called by the T.BAT batch file. Run "COPY_711.BAT" to copy the folder to the hard drive. This program will automatically run the test program for the card (which can be run thereafter by typing "P" at the C:>\ prompt). Set CARDTYPE to "PCL711b" and the address to "220", unless it has been changed to prevent conflicts. The manual for the card contains information on changing the address jumper settings.

Acrobat505.EXE - This file installs Adobe Acrobat 5.05 in Windows to allow access to the PDF files.

CDROM.BAT - This copies the necessary files from a folder of the same name to allow DOS to recognize the CD-ROM drive. Just run "CDROM" at the prompt for the CD_ROM drive after configuring (partition and format) the system with the boot floppy. This should not be run if there is no CD-ROM in the computer.

README.TXT - A file containing this document. It is also available as a self-running executable file viewer, README.EXE and has navigation instructions in the file. Type "README" at the C:>\ prompt.

Note : The CD-ROM is bootable for systems that support starting from the CD. It also contains FDISK.EXE for checking the hard drive properties and SCANDISK.EXE for checking the condition of the hard drive, if needed. Partitioning and formatting the hard drive should be done using the boot disk created with WINSTART.EXE.